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EVOLUTION OF EARLY PALEOZOIC FAUNAS IN RELATION TO THEIR ENVIRONMENT[1]

CHARLES D. WALCOTT

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INTRODUCTION

The evolution of early Paleozoic faunas could be treated with far greater effectiveness if the studies now in progress on the Cambrian faunas were nearer completion. That of the brachiopods is well advanced[2] but the great collections of the U. S. National Museum, representing the crustacea and other invertebrates, have not been studied as to their mode of occurrence, geographic distribution, and biologic and environmental relations. Only a brief summary of the known evidence afforded by the Cambrian rocks and faunas of North America is considered in this paper.

Animals and plants, as now known, are profoundly influenced by

[1] Read before Section E of the American Association for the Advancement of Science, Baltimore meeting, December, 1908.

[2] *Smithsonian Miscellaneous Collections*, Vol. LIII, No. 4, 1908, pp. 139–65.

their environment, hence we will first broadly outline the conditions under which the known marine organisms of Cambrian time lived.[1]

NORTH AMERICAN CONTINENT AT THE BEGINNING AND AT THE CLOSE OF CAMBRIAN TIME

The information obtained since the publication of my first map on this subject in 1891[2] has been assembled on the two accompanying maps by Mr. Bailey Willis. The first map outlines a central mass of pre-Cambrian land, flanked on either side by large barrier islands that served to protect straits, sounds, or seas from the open ocean. Ocean currents flowed through the sounds with varying force and volume, not only from the cold arctic waters to the north, but from the warm tropical region to the south. The relative position of land and sea is based on the present interpretation of the observed characters and distribution of the pre-Cambrian and Lower Cambrian rocks. The distribution of Lower Cambrian faunas indicates the probable courses of the marine currents. A fundamental assumption is that the great ocean basins and continental masses occupied their present relative positions during at least the Algonkian portion of pre-Cambrian time.

The map of the continent at the close of Cambrian time shows that during this period upon the continental area marked changes in the positions of the land and sea took place. Broad shallow seas followed the transgressing shore-line of Middle Cambrian time, offering most favorable conditions for the long-continued development and distribution of marine life.[3] There were undoubtedly deep and shallow seas and bays, cold and warm waters, strong and weak ocean currents of unlike temperatures, protected bays with sandy and muddy bottoms, shore lines gently sloping to deep water, and many conditions promoting the evolution of the faunas through favorable or unfavorable changes in environment, temperature, and food-supply.

The sediments of Cambrian time are mainly those deposited near the shore-line and in adjacent relatively shallow waters. There is little if anything to indicate deposits of the abyssal sea. If the littoral

[1] *Bull. Geol. Soc. Amer.*, Vol. X, 1899, pp. 199–244.

[2] *Bull. U. S. Geol. Survey*, No. 81, 1891, Pl. III.

[3] See theoretic section at the close of Cambrian time: *Bull. U. S. Geol. Survey*, No. 81, 1891, Pl. II.

fauna of the Cambrian sea had begun to work its way down the continental slopes beyond the continental margin into the depths, we can find no evidence of it, either in the Cambrian rocks, or in the character of the present deep-sea fauna.

The life of Lower Cambrian time included Crustaceans (trilobites, ostracods), Mollusca (gasteropods), Molluscoidea (brachiopods), Vermes (annelids), Echinodermata (cystoids), Coelenterata (sponges, corals, jelly-fishes), and the simplest animals, the Protozoa (rhizopods). Immense quantities of microscopic, unicellular plants were undoubtedly present, and, together with the minute Protozoa, must have formed the primary food-supply.[1]

The rôle assigned by Dr. W. K. Brooks to microscopic forms was an important factor in Cambrian time, for the organisms found in the rocks of that period were mainly carnivorous, and were adapted either to straining minute organisms from the water, or to gathering them up from the bottom.

Uniform marine physical conditions over the submerged portions of the continental platform in Lower Cambrian time are indicated by the uniformity of the fauna on opposite sides of the present continent. Whether this fauna was distributed between the east and the west to the north of the central land-area, or south of it, is not definitely determined, yet the absence of Lower Cambrian rocks and fossils from the collections made in the Arctic region, and the presence of closely allied species in the Lower Cambrian rocks of Alabama and California, point to the southern coast-line as the probable highway for the distribution of the littoral fauna. Nothing that suggests the Lower Cambrian fauna is known from South America; in this case, deep water may have been the barrier.

With the advent of Middle Cambrian time land-areas came into existence on the northeast, forming barriers which so affected marine conditions in relation to life that the Paradoxides fauna developed in the Atlantic basin and the Olenoides fauna in the Appalachian region south of the Champlain Valley. To the south and on all sides of the

[1] W. K. Brooks, *Studies from the Biological Laboratory, Johns Hopkins University*, Vol. V, 1893, pp. 136–38. On p. 137 Dr. Brooks says: "The simplicity and abundance of the microscopic forms and their importance in the economy of nature show that the organic world has gradually shaped itself around and has been controlled by them."

central land-area the advancing seas forced the faunas to shift their habitat and either to adjust themselves to the new conditions or to perish. Local isolation for long periods led to the development of new forms, and these, when the barriers were removed, contested and competed for their position and life with other faunas until, by a process of elimination of those least fit to survive, there was hastened the development of a large and varied fauna. With the close of Middle Cambrian time more stable conditions returned, and the era of rapid evolution was checked until the impulse of new conditions of environment and an accumulated tendency to change resulted in the great evolution of life in the lower Ordovician.

LIFE AT THE BEGINNING OF KNOWN CAMBRIAN TIME

The traces of pre-Cambrian life, though very meager, are sufficient to indicate that the development of life was well advanced long before Cambrian time began. The characteristic fossil of the known pre-Cambrian fauna is *Beltina danai*,[1] a crustacean probably more highly organized than the trilobite. The associated annelid trails indicate that this phase of the fauna was also strongly developed. Stratigraphically, this fragment of what must have been a large fauna occurs over 9,000 feet beneath an unconformity at the base of the upper portion of the Lower Cambrian in northern Montana.[2] This fact indicates that it is practically hopeless to search for the first forms of life—those that could leave a trace of their existence—in strata now referred to the Cambrian or early Paleozoic. With this thought in mind we shall consider what is known of the life of early Lower Cambrian (Georgian) time.

The oldest known Cambrian fossils are found deep down in the Lower Cambrian strata of southwestern Nevada and the adjoining Inyo County area of eastern California. In sections 120 miles apart the Lower Cambrian has a thickness of over 5,000 feet, with a great limestone forming the upper 700 to 2,000 feet. Below this limestone calcareous strata occur, but the predominating rocks are sandstones, and arenaceous, siliceous, and calcareous shales. In the lower 400

[1] *Bull. Geol. Soc. Amer.*, Vol. X, 1899, pp. 238, 239.

[2] C. D. Walcott, *Observations of 1908*.

feet of the Waucoba Springs section and the Barrel Spring section south of Silver Peak in western Nevada[1] the fauna includes:

Annelid trails
Protopharetra, sp. undt.
Archaeocyathus, sp. undt.
Ethmophyllum cf. *whitneyi* Meek[2]
Mickwitzia occidens Walcott[3]
Trematobolus excelsis Walcott[4]
Obolella, sp. undt.
Orthotheca, sp. undt.
Holmia rowei, new species
Holmia weeksi, new species

Although this fauna, according to our present knowledge, is the oldest known Cambrian fauna, it includes representatives of the several classes of invertebrates which I will enumerate.

Actinozoa.—The corals are represented by a very primitive form of *Protopharetra*, a small form of cup-shaped *Archaeocyathus*, and a small *Ethmophyllum* closely allied if not identical with *Ethmophyllum whitneyi* (Meek),[5] which occurs higher in the section. The latter is not a notably simple or primitive form of the Archaeocyathinae; on the contrary, it is nearly as far advanced as any species known in the Cambrian.

Vermes.—The annelid borings and trails that occur in and on the sandstones and shales are much like those of the Middle and Upper Cambrian.

Molluscoidea.—The two species of brachiopods represent widely separated genera. *Mickwitzia occidens* Walcott[6] is one of the primitive forms of the Paterinidae, while *Trematobolus excelsis* Walcott[7] is a typical form of the Siphonotretidae. The interval represented by the relative development of *Mickwitzia* and *Trematobolus* is sufficient to convince us that we must look far back in Cambrian, or it may be pre-Cambrian, time for the progenitors of the inarticulate brachiopods.

[1] Walcott, *Smithsonian Miscellaneous Collections*, Vol. LIII, No. 5, 1908, pp. 185–89.

[2] See *Bull. U. S. Geol. Survey*, No. 30, 1886, pp. 81–84.

[3] *Smithsonian Miscellaneous Collections*, Vol. LIII, No. 3, 1908, p. 143.

[4] *Ibid.*, p. 146.

[5] *E. gracile* is considered to be a synonym of *E. whitneyi* (*Bull. U. S. Geol. Survey*, No. 30, 1886, pp. 81–84).

[6] *Smithsonian Miscellaneous Collections*, Vol. LIII, No. 3, 1908, p. 143.

[7] *Ibid.*, p. 146.

Pteropoda.—The forms representing *Orthotheca* are abundant, large, strong, and evidently as well developed as those of the Middle Cambrian.

Crustaceans.—The trilobites thus far found at this horizon are confined to two species of the genus *Holmia*. One of them, *Holmia weeksi*, new species, has many segments, and is more primitive than such forms as *Olenellus thompsoni* Hall[1] and *Holmia bröggeri* (Walcott)[2] of the upper portions of the Lower Cambrian section. The other species, *Holmia rowei*, new species, is of the same general type as *Holmia bröggeri*. The absence of all other trilobite genera is the most marked feature of this early Cambrian fauna.

In the section 100 miles to the south, at Resting Springs, Inyo County, California, a brachiopod closely related to *Billingsella highlandensis* Walcott[3] occurs 2,800 feet below the upper limestone, in association with the trilobite *Holmia rowei*.

Comparing the species in the early Lower Cambrian fauna with the Olenellus fauna, in strata 5,000 feet higher in the section, we find a marked advance in the variety of the later fauna, but we do not know how much of this may be due to the absence, from our collections, of genera and species that may have existed during the deposition of the earlier sediments. In the earlier fauna of the Waucoba section the class characters of the Arthropoda, Mollusca, Molluscoidea, Vermes, and Coelenterata were developed, and while the study of the genera and species adds a little more to our knowledge of the rate of convergence backward in geologic time of the lines representing the evolution of animal life, it, at the same time, proves that a very long time-interval elapsed between the beginnings of life and the epoch represented by the Olenellus fauna.[4]

DISTRIBUTION OF THE LOWER CAMBRIAN (OLENELLUS) FAUNA OVER THE NORTH AMERICAN CONTINENTAL PLATFORM OF CAMBRIAN TIME

The Olenellus fauna lived on the eastern and western sides of a continent that rudely outlined, in its general configuration, the North

[1] See *Bull. U. S. Geol. Survey*, No. 30, 1886, p. 167.

[2] See *Tenth Annual Report, U. S. Geol. Survey*, 1891, p. 638.

[3] *Proc. U. S. National Museum*, Vol. XXVIII, 1905, p. 237.

[4] *Tenth Annual Report, U. S. Geol. Survey*, 1891, p. 595.

American continent of today. Strictly speaking the fauna did not live upon the outer shore facing the ocean, but on the shores of interior seas, sounds, straits, or lagoons that occupied the intervals between the several land-masses that rose from the partly submerged continental platform east and west of the central continental area. On the eastern side, the first land east of the central portion of the continent extended from Alabama northeast along the line of the present Appalachian range to and including the Green Mountains of Vermont. Whether or not the fauna existed in the Connecticut River region to the east of the Green Mountains is unknown. That it occurred further east is shown by its presence in eastern Massachusetts and northwestern Newfoundland. Its presence in a still more easterly basin is proved by its occurrence on the peninsula of Avalon, to the east of the area of Archean rocks crossing central Newfoundland.

It is not my intention to discuss the evidence upon which the assertion of the presence of these various outlying seas, sounds, etc., is based. The evidence of the existence of such bodies of water has been well presented by Dana.[1] What I wish to call attention to now is that the Olenellus fauna lived upon the eastern and western sides of the main North American continental area of late Algonkian and early Cambrian time. This view is sustained by the following observations: (1) The strata containing the Olenellus fauna are known only in the eastern and western portions of the continent; (2) as far as known the Lower Cambrian strata are absent in the interior of the continent; (3) the Upper Cambrian strata are unconformably superjacent to the Algonkian and Archean rocks over the areas where the Middle and Lower Cambrian formations are absent; (4) the strata of the Middle and Lower Cambrian are comformably beneath the Upper Cambrian on the eastern and western sides of the present continent in all sections where the three divisions are present.[2]

The oldest known portion of the Olenellus fauna is limited to that

[1] "Areas of Continental Progress in North America, and the Influence of the Conditions of These Areas on the Work Carried Forward within Them." *Bull. Geol. Soc. Amer.*, Vol. I, 1889, pp. 36–48. "Archean Axes of Eastern North America," *Am. Jour. Sci.*, 3d ser., Vol. XXXIX, 1890, pp. 378–83.

[2] The matter contained in the two preceding paragraphs appeared under the heading "Habitat of the Olenellus Fauna" in the *Tenth Annual Report, U. S. Geol. Survey*, 1891, pp. 556, 557.

section of the Cordilleran area mentioned on p. 197. This fauna was undoubtedly present on the continental shelves to the north and south, and may have been distributed around the southern extremity of the central land-area to the Hudson and Champlain valley region. Future investigation may thus prove that the *Holmia asaphoides* fauna[1] of eastern New York is the oldest part of the Olenellus fauna upon the eastern side of the continent, and that it may be compared with the *Holmia rowei* fauna of the Cordilleran area. The presence in both localities of genera belonging to the Archaeocyathinae indicates that warm currents were passing through the straits or sounds to the east and west of the central continental areas, and that conditions were favorable for a varied fauna. The arenaceous beds (with ripple-marks and trails) of the western Nevada-California area and the interformational conglomerates of eastern New York prove the presence in both areas of relatively shallow water.

The *Olenellus thompsoni* fauna,[2] of late Lower Cambrian time, is widely distributed about the margins of the continental area. Beginning at the Straits of Belle Isle on the northeast, it has been found in eastern Massachusetts, western Vermont, eastern New York, eastern Pennsylvania, and along the Appalachian area as far south as central Alabama. In the Cordilleran area it is known to extend from Inyo County, California, to the Wasatch Mountains of Utah, and northward to the line of the Canadian Pacific Railway in British Columbia.

With the exception of vertebrates, echinoderms, and cephalopods, the class-characters of the early Lower Cambrian fauna of Nevada were well advanced toward the varied and rich fauna of the lower Ordovician.

CONDITIONS DURING MIDDLE AND UPPER CAMBRIAN TIME

The physical conditions of the late Lower Cambrian time continued into early Middle Cambrian time, followed during Middle Cambrian time by a gradual submergence through erosion and probable warping of the surface of most of the continental area south of the Great Lake region.[3] As the marine waters slowly encroached upon this great area and upon the shores adjoining the Appalachian and Cordilleran

[1] *Tenth Annual Report, U. S. Geol. Survey*, 1891, p. 570.

[2] *Ibid.*, p. 569.

[3] *Am. Jour. Sci.*, Vol. XLIV, 1892, pp. 56, 57.

seas the marine life of the times met with conditions favorable to a large development. This is illustrated by the abundant and varied Paradoxides fauna on the Atlantic side and the equally varied Pacific basin Olenoides[1] fauna found in nearly all localities where the Middle Cambrian sediments were deposited.

EVOLUTION OF FAUNAS

That the environment of the faunas of Middle Cambrian time was more favorable for their rapid evolution than that of Lower and Upper Cambrian time is strikingly shown by the stratigraphic distribution of the brachiopods. In the restricted waters of Lower Cambrian time the known brachiopods (of the entire world) were represented by 20 genera and 75 species. In the expanding seas of Middle Cambrian time 31 genera and 243 species are known to have existed. With the more uniform conditions of Upper Cambrian time, and the dying-out of the impulse to variation created by both favorable and unfavorable environments in Middle Cambrian time, the brachiopods decreased in variety and numbers, and are represented by only 23 genera and 137 species.

About the same relative numerical ratios are exhibited by the trilobites but the exact statistics are not yet available. The favorable environment of the Middle Cambrian fauna is well illustrated by the development of *Ogygopsis*, *Asaphiscus*, and *Bathyuriscus* of Cordilleran Middle Cambrian time,[2] genera which are so far in advance of contemporary trilobitic genera that they have sometimes been referred, upon biological grounds, to the Upper Cambrian.[3]

The closing of Cambrian time was accompanied and followed by changes in the relations of the sea and land upon the continental platform that were favorable, like those of Middle Cambrian time, to the

[1] The Olenoides fauna is found on both the eastern and western sides of the northern Pacific Ocean, and the Paradoxides fauna on both sides of the northern Atlantic Ocean. This fauna includes a group of trilobites that are represented more or less fully in the Middle Cambrian rocks of North America, east of the Atlantic basin Paradoxides faunas, and in eastern Asia. The fauna includes: *Olenoides* Meek, *Dorypyge* Dames, *Neolenus* Matthew, *Dorypygella* Walcott, *Damesella* Walcott, *Blackwelderia* Walcott, *Zacanthoides* Walcott, and *Kootenia* Walcott.

[2] See *Bull. U. S. Geol. Survey*, No. 30, 1886, Pls. XXX, XXXI, and *Canadian Alpine Journal*, Vol. I, No. 2, 1908, Pl. 3.

[3] G. F. Matthew, *Trans. Roy. Soc., Canada*, 2d ser., Vol. V, 1899, p. 64.

evolution of new genera and species, and to the existence of multitudes of individuals of the prolific species.

This is not the place for a detailed discussion of the faunas and sediments of the lower Paleozoic. Only the broadest generalizations can be touched upon. I think, however, that sufficient has been said to fix in your minds the following conclusions: (1) That more or less uniform and favorable, even warm, climatic conditions must be appealed to in explanation of the widespread occurrence of almost identical coral-like organisms in the Lower Cambrian, and of the vast number of individuals of various species of trilobites, etc., which existed in Middle Cambrian time; (2) that the rapid and accentuated development of the Middle Cambrian faunas was due in great measure to enlarged opportunity caused by the extension of the Cambrian seas and the consequent shifting of shore-lines and changes in habitat, etc.; (3) that the diversification of the Middle Cambrian fauna, as a whole, may have been due, in a large degree, to the rapid development of narrowly provincial or isolated faunas that were subsequently merged into the more widely distributed fauna by the breaking-down of the restrictive barriers; and (4) that a free and more or less complete interchange of currents in the Cambrian seas was strongly instrumental in producing those cosmopolitan faunas so characteristic of the early Paleozoic. In other words it is evident that the evolution of the early Paleozoic faunas was profoundly influenced by their environment.

PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

BAILEY WILLIS
U. S. Geological Survey

At the Baltimore Meeting of the American Association for the Advancement of Science a number of paleogeographic maps of North America, representing the continent at intervals from Cambrian to Quaternary, were exhibited. They had been prepared in collaboration with some of the geologists who presented papers in the symposium on correlation, and to a certain extent they serve to illustrate the changing geologic conditions which form a factor in the problems of correlation. I have been requested to publish them in connection with the correlation papers in the *Journal of Geology*, and am glad to do so, although it is not practicable to present a discussion of the particular facts which have been considered in the construction of each individual map.

In general the lines of evidence have been considered somewhat in the following manner.

A certain period having been selected as that which should be mapped, the epicontinental strata pertaining to that time interval have been delineated. The phenomena of sedimentation and erosion have then been correlated, with a view to determining the sources of sediment and topographic conditions of land areas, and from these data the probable positions of lands have been more or less definitely inferred. Thus, certain areas within the continental margin are distinguished as land or sea, and these areas may be defined as separate bodies or connected according to inferences based upon isolated occurrences or upon later effects of erosion.

It is assumed that the great oceanic basins and such deeps as the Gulf of Mexico and the Caribbean have been permanent features of the earth's surface at least since some time in the pre-Cambrian. These deeps can thus be placed upon the map and their connection with the epicontinental seas may be tentatively established.

When the distribution of lands and waters is thus inferentially

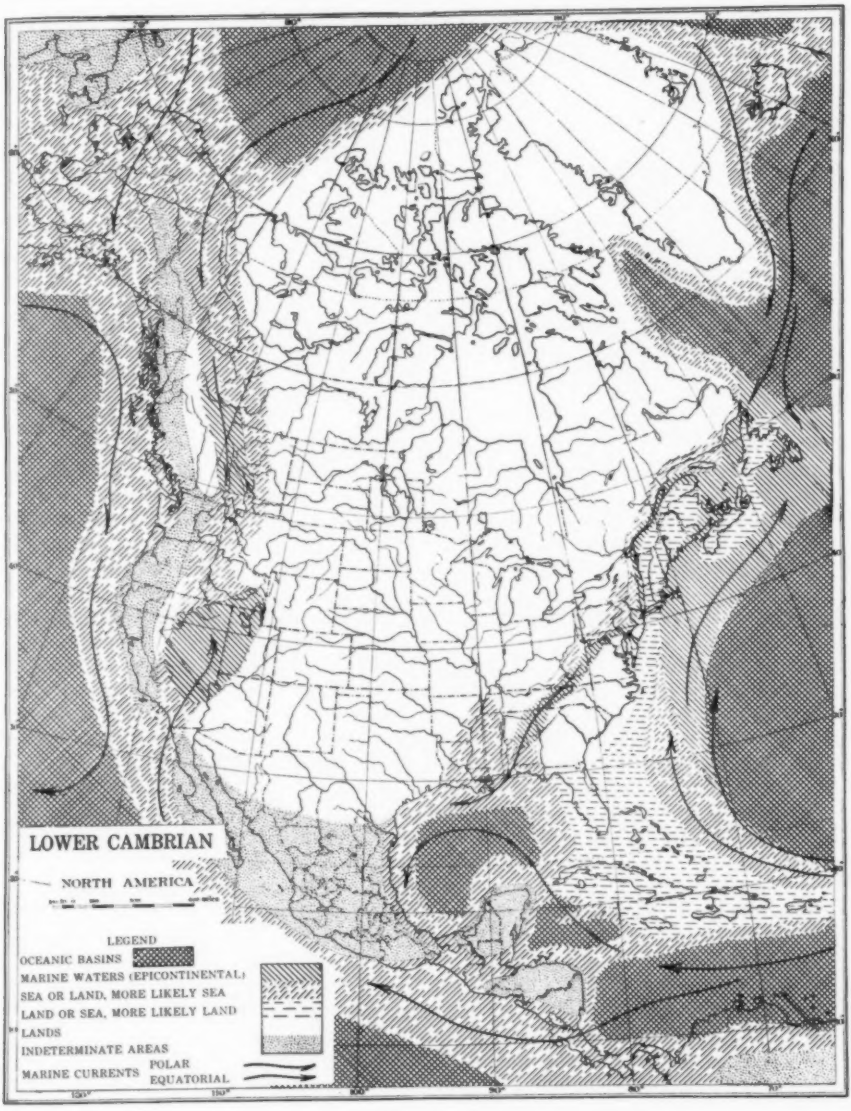
[1] Published by permission of the Director of the U. S. Geological Survey.

completed, we may infer further that the dominant features of oceanic circulation have obeyed the conditions of atmospheric circulation and of rotation of the sphere which now govern the great oceanic eddies. We may introduce in the Atlantic and Pacific the dominant drifts from east to west in equatorial regions with the resulting circulation northward along the east coast and southward along the west coast of the continent. A circulation of the oceanic waters in the epicontinental seas must result from the great oceanic drifts, and the direction of flow will be determined by the configuration of the lands and the depths of the seas.

From the geographic conditions thus developed inferences regarding the climate and the life habitats of the time may be drawn. If now we turn to the records of paleontology and compare the distribution of faunas and floras with the conditions of distribution which should result from the inferred physical phenomena, we may check the whole line of reasoning and by a readjustment draw a step nearer to the truth. This is the method which has been pursued in making the maps of North America that are published with the papers in this number and that will appear in connection with further papers of the series.

In a first essay of this kind (and I am not aware of any earlier attempt to combine the various lines of evidence in a similar manner) it is probable that important facts have been overlooked. The very broad scope of the discussion makes this probability almost a certainty, and it is not to be expected that the maps here presented should give a final or satisfactory solution of the problems. They are to be regarded as tentative and suggestive only.

On one point they have been particularly criticized, it being said that each individual map covers so long a period of time and such diverse conditions that they do not truly represent any special geographic phase of the continent. This criticism is valid, and one of the steps in the advancement of knowledge will be that of selecting narrower time limits and more precise correlations than have been attempted in these cases. We may undoubtedly make progress in this direction at the present time so that the fifteen maps which will accompany this series may be replaced by two or three times as many; but there is danger in carrying the refinements too far on the


LOWER CAMBRIAN
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS
POLAR
EQUATORIAL

basis of paleontologic correlation alone, since it is still difficult to distinguish between synchronous and homotaxial faunas or floras. It may be hoped that these paleogeographic studies will themselves assist us to a better understanding of the evolution of life conditions and thus lead to a solution of some of the problems of correlation with the aid of biologic evidence.

1. LOWER CAMBRIAN NORTH AMERICA

The map of lower Cambrian North America presented herewith conforms to the outline developed by Mr. Walcott in the course of his studies. East and west of the central land mass are relatively narrow sounds limited on the oceanic side by islands or land masses of indeterminate extent. The old land area of Appalachia is believed to have covered the region of the West Indian Islands, it being well established that a somewhat extensive land extended to the southeast of the Appalachian trough, and it being plausible that that land lay between the Atlantic deep on the northeast and the deeps of the Caribbean and Gulf of Mexico. In the adaptation of marine currents to oceanic and continental features, it is inferred that the return waters from the Arctic occupied the sounds along the inner continental margins. The distribution of these currents suggests that the habitat of the lower Cambrian fauna of the Appalachian trough on the east and the British Columbia-Nevada trough on the west was determined by the cool waters flowing southward. This view of dispersion of the faunas from the north is not shared by Mr. Walcott, who presents the alternative hypothesis of a connection of the faunas around the southern margin of the continent. The fauna of the Nevada basin appears to belong to warmer waters than that of British Columbia, inasmuch as it contains corals. The land areas of lower Cambrian time throughout the northern hemisphere appear to have been large. There is evidence in the character of the sediments and in glacial deposits in China that there were marked contrasts of climate.

2. LATE MIDDLE AND UPPER CAMBRIAN NORTH AMERICA

The map of late middle and upper Cambrian North America represents an expansion of the area of the epicontinental sea which probably was not at any time actually reached. The middle Cam-

LATE MIDDLE AND
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POLAR
EQUATORIAL

brian sea extended further in certain areas than the upper Cambrian and retreated while the upper Cambrian sea spread over other regions. These details are not well worked out, though in part recognized. The map truly presents, however, the general fact that North America was to a great extent submerged and the land areas very markedly reduced. The prevailingly fine and calcareous sediments of the wide seas and the siliceous coastal plain sediments of the littoral deposits indicate that the relief of the land was low.

The conditions of marine circulation had apparently been modified by the expansion of the interior sea, and the climate conditions incident to widespread seas and low lands had become so ameliorated that similar habitats prevailed throughout a very wide range of latitude.

PHYSICAL AND FAUNAL EVOLUTION OF NORTH AMERICA DURING ORDOVICIC, SILURIC, AND EARLY DEVONIC TIME

AMADEUS W. GRABAU
Columbia University

IV

The following classification of the Ordovicic[1] and Siluric has recently been published by the author and will be made the basis of the present discussion of these systems:[2]

F. Upper Siluric or *Monroan*.
E. Middle Siluric or *Salinan*.
D. Lower Siluric or *Niagaran*.
C. Upper Ordovicic or *Trentonian*.
B. Middle Ordovicic or *Chazyan*.
A. Lower Ordovicic or *Beekmantownian*.

A. THE LOWER ORDOVICIC OR BEEKMANTOWNIAN

At the beginning of Ordovicic time, as now generally recognized, the great marine transgression or positive diastrophic movement, which obtained throughout Upper Cambric time, was in progress, so that the early Beekmantown strata overlapped the Upper Cambric (Saratogan) and came to rest directly upon the crystalline basement. The basal portion of the sedimentary series is generally quartz sandstone of greater or less purity, or sometimes a conglomerate with crystalline pebbles of local origin. This basal sandstone is commonly referred to the "Potsdam," that term being used synonymously with Upper Cambric. Aside from the question as to whether or not the Potsdam sandstone of the type locality is really of Upper Cambric age, it must of course be apparent that in a normally overlapping series of strata deposited by a transgressing sea, the basal sand member would naturally rise in the series in the direction of transgression and overlap, and that hence a basal sand is not everywhere of the same age. In northwestern New York, in Ontario, and in northern Michigan, these basal sands are probably in all cases

[1] This journal does not approve the terms "Ordovicic," "Siluric," etc.

[2] *Science*, N. S., Vol. XXIX, pp. 351–56, February, 1909.

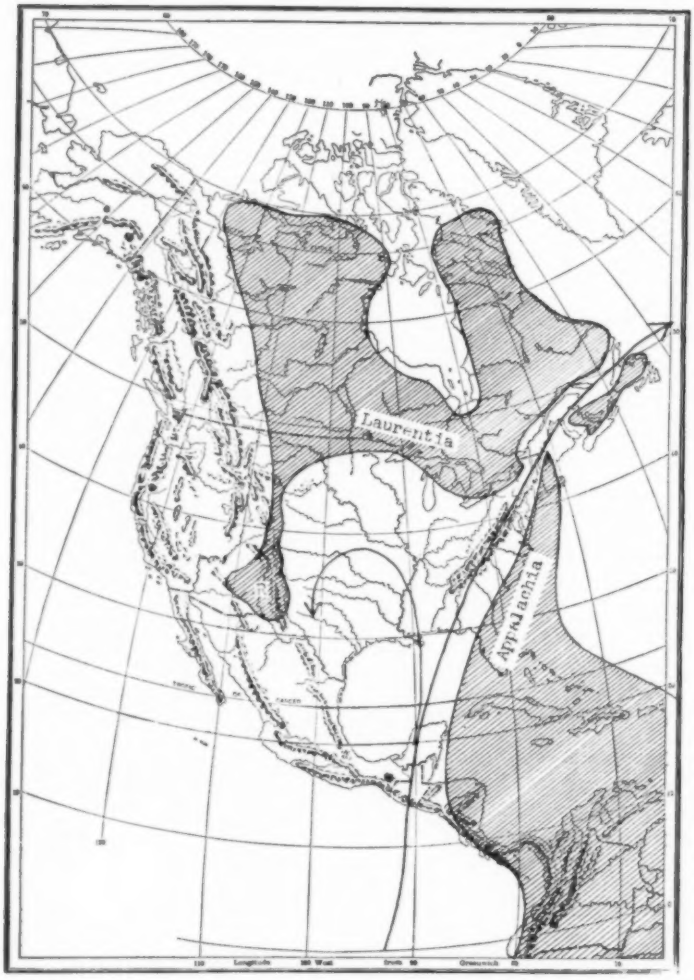


Fig. 1.—Paleogeographic map of North America at end of Upper Cambric time, and probable currents. R. Peninsula of Rockymontana.

post-Saratogan, belonging to the basal portion of the Beekmantown series as generally defined. This is clearly true of the conglomeritic layer at the base of the Little Falls dolomite in the Mohawk Valley, and is probably also true of the so-called Potsdam of the Black River region and the westward continuation of the outcrop in Canada. There is good reason for believing that the sea at the end of Saratogan time did not cover the present site of Lake Ontario, and that the basal sandstones of the Ontario region belong to the base of the overlapping early Beekmantown. In some cases the basal sands (St. Mary's sands) are even younger than this (Lowville, N. Y., Encampment d'Ours, Isle Lacloche, etc.), for the immediately overlying strata carry late Chazy (Lowville) or even Black River fossils, and, so far as now known, there is no break in sedimentation between these basal sands and the beds immediately succeeding, which thus determine their age. In all such cases, until positive evidence of a pronounced physical break or disconformity is determined between the two series, or until the basal bed is shown by unquestionable fossil evidence (exclusive of Scolithus, burrows, trails, and other problematic markings which may characterize various Paleozoic sandstones) to be of Cambric age, logical reasoning compels us to regard the age of the basal sandstone in each case as essentially that of the fossiliferous beds immediately succeeding, unless these are the very lowest post-Cambric beds.

One other point should be clearly emphasized. It is by no means established that the basal sandstones are everywhere of marine origin. In fact, the general absence of fossils, the frequent cross-bedding and other characters point rather to a continental origin of a part, at least, of this basal series, the agents of deposition being rivers or the wind. There is scarcely a geologist today who is satisfied with the complacent explanation, current only a short time ago, that the absence of fossils in a sandstone is due to "unfavorable conditions at the time of deposition," or to subsequent destruction of the fossils, in some mysterious way or other. That fossils abound in marine sandstones of all kinds, and even in conglomerates, is a well-known fact, and that the sands along our modern sea-shores are rich in shells and other hard parts of organisms, is equally a matter of common knowledge. The argument that the absence of fossils in a

rock which elsewhere carries them, indicates some peculiarity of the sea-shore at that point, capable of barring the life of the sea, is a laborious explanation to fit a preconceived notion of the origin of the formation in question. Nor must we forget that the North American continent was above the sea during long periods of pre-Cambric and Cambric time, and that on those vast land areas subaërial deposition as well as erosion must have been in progress. It is therefore to be expected that in many, if not in most, regions the Paleozoic series begins with a formation of continental origin, the upper portion of which was reworked by the transgressing sea, and became incorporated as a basal member of the marine series succeeding. In this manner the contact between the continental and marine series often became an apparently conformable and perfectly gradational one, the hiatus between them being masked. It will of course be impossible in such a case to determine whether a basal bed of continental origin is of pre-Cambric, of Cambric, or of post-Cambric age; all that can be determined is the period at which its upper portion was reworked by the transgressing sea. If the basal bed is of slight thickness it is in such a case best referred to the age of the immediately succeeding marine formation.

The question naturally arises, should the lower portion of the Beekmantown be referred to the Cambric with which it forms a continuous transgressive series, or should it be retained in the Ordovicic with the remainder of the Beekmantown? While in New York the fauna is, so far as known, an Ordovicic one, in other localities beds considered of the same age carry a mixed Cambric and Ordovicic fauna. In this respect these beds and the typical Saratogan, as well as the St. Croix series of Minnesota and Wisconsin, probably correspond to the Tremadocien of Europe, which is classed as Upper Cambric by British geologists, but by German and other continental geologists as basal Ordovicic (Unter Silur). Matthew correlates these beds with the *Asaphellus homfrayi* beds of the St. John section, and so places them above the *Dictyonema flabelliforme* beds, which at present are also included in the base of the Ordovicic by some continental geologists. That such transitional formations are to be expected in any complete depositional series is, of course, obvious, and their precise reference is a matter of secondary importance.

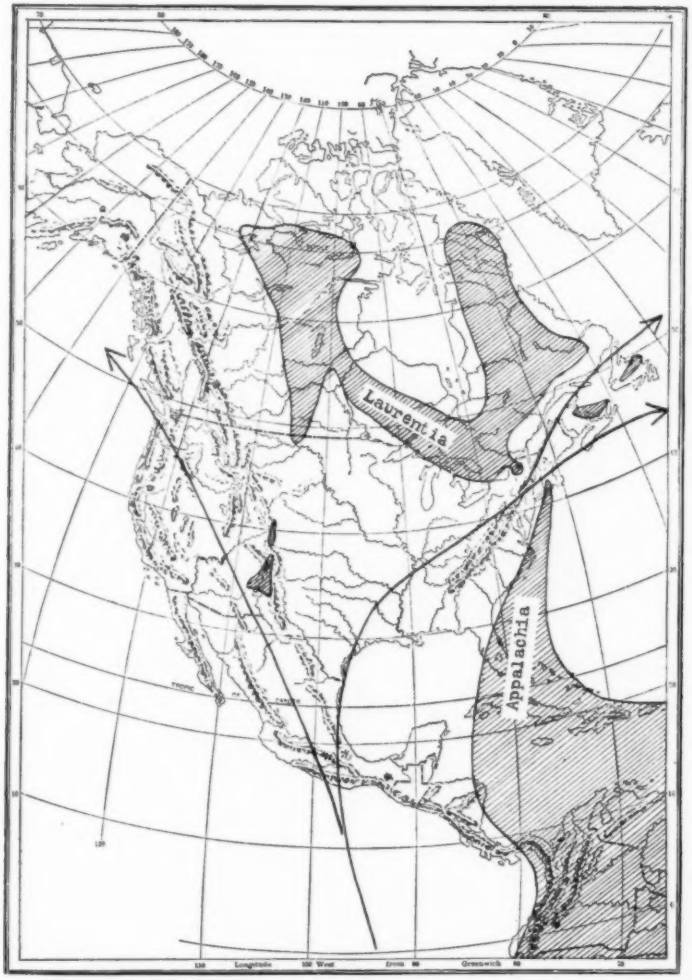


Fig. 2.—Paleogeographic map of North America in early Beekmantownian time, showing extent of maximum transgression and probable currents.

To make a distinct system of them, as has been proposed by some, will not solve the difficulty, because the transitional beds are likely to be of very variable quantitative and chronologic values in different localities. The accepted base of the Ordovicic,—the summit of the Saratoga formation in New York, of the Franconia sandstone in the Mississippi Valley, and of the *Asaphellus homfrayi* beds on the Atlantic coast, is a perfectly satisfactory one, as long as the synchroneity of these formations is granted. (Compare Figs. 1 and 2.)

REGRESSIONAL PHASE OF THE BEEKMANTOWN

As has been fully demonstrated by the author elsewhere[1] and by Berkey,[2] the chief event of Beekmantown time in North America was the widespread regressive movement of the sea and the re-emergence of the continent. The extent of the movement is shown by the extensive disconformity between the Beekmantown and the succeeding Chazy formations. From this it appears that only a narrow trough remained in the Appalachian region as the sole representative of the interior or Mississippian sea, while most of the Pacific coast region, west of the Rocky Mountains axis, was probably uncovered (see map, Fig. 3). In the interior of North America the emergence was accompanied by widespread continental deposition recorded in the St. Peter sandstone. The detailed characteristics of this formation; the all but complete absence of fossils; the cross-bedding shown in many exposures; the rounded character of the sand grains, their grooved and pitted surfaces; the absence of the finer impurities; the uniformity of the size of grain in the same region—all point to long-continued shifting about of these sands by winds, and testify against their marine origin. The inclusions in the quartz grains show them to be derived from the crystalline oldland, the chief source being probably the Canadian shield. In some cases the contact with the underlying formations is abrupt and disconformable, showing that erosion of the uncovered limestones preceded the deposition of the sands. Not infrequently the contact

[1] Grabau, A. W., "Physical Characters and History of Some New York Formations," *Science*, N. S., Vol. XXII., pp. 528 ff., October, 1905; also, "Types of Sedimentary Overlap," *Bull. Geol. Soc. Amer.*, Vol. XVII, pp. 616 ff.

[2] Berkey, C. P., "Paleogeography of St. Peter Time," *Bull. Geol. Soc. Amer.*, Vol. XVII, pp. 229–50.

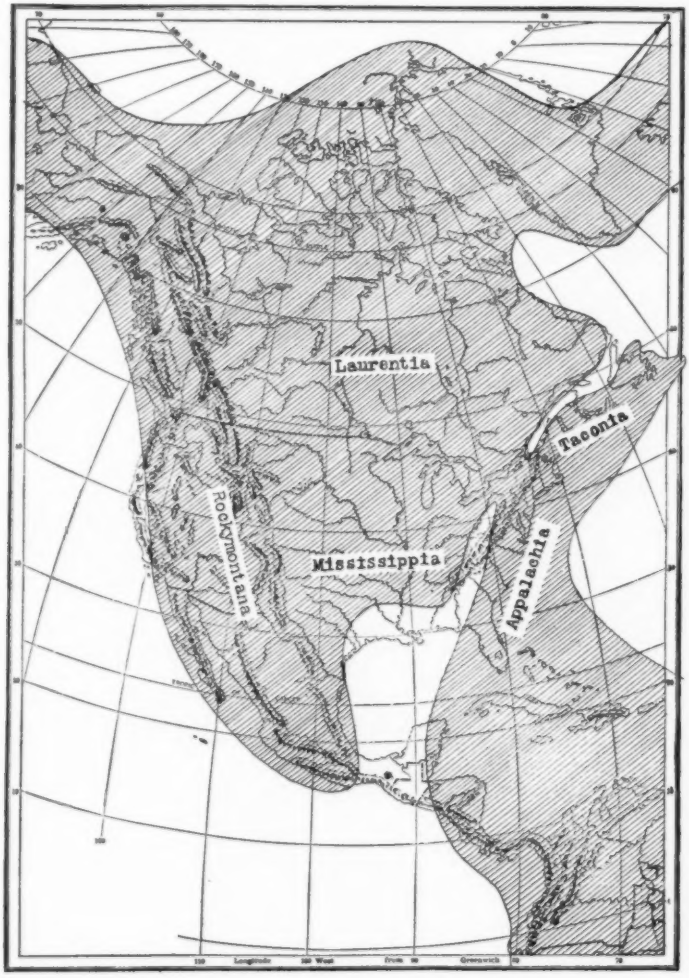


Fig. 3.—Paleogeographic map of North America at the end of Beekmantownian time, showing maximum retreat of the sea.

is as sharply marked as that of aeolian quartz sands found upon the clear-swept limestone floors of some modern deserts.[1] In some cases, however, there appears to be absolute conformity between the St. Peter sandstone and the underlying dolomites, pointing to continuous deposition. Both in Wisconsin and in Minnesota, the lower Magnesian beds are often slightly folded, and the lower St. Peter sandstone is likewise involved in these folds[2] (Fig. 4). The upper St. Peter, however, and the overlying Stones River, which are perfectly conformable, are not involved in these folds. In Minnesota, the Oneota, New Richmond, and Shakopee formations have a combined thickness of 105 to 260 feet. If the Jordan and St. Lawrence beds are regarded as Ordovicic, though they still contain Dicellocephalus, the thickness is increased to 190 feet minimum or 673 feet maximum. The faunas of all the beds of the Lower Magnesian series indicate lowest Ordovicic and close relationship to the Upper Cambric. In the Black River region, Cushing records 20 to 60 feet of lowest Beekmantown (Theresa), succeeded disconformably by Upper Chazy (Pamelia and Lowville limestones). The base is probably not exposed in this section, the basal sandstone, called Potsdam by Cushing, being most likely of later age. In the Mohawk Valley, 350 feet of Beekmantown (Little Falls dolomite) is followed disconformably by Upper Chazy (Lowville); but here, too, the base of the Beekmantown is not shown, and hence the true thickness is unknown. In the Lake Champlain region the Beekmantown is 1,800 feet thick; in southern Pennsylvania 2,250 to 2,300 feet; in central Pennsylvania nearly 2,500 feet; and in the Arbuckle Mountains of Oklahoma 1,250 feet. In all these localities, except central Pennsylvania, the upper limit of the Beekmantown is marked by a dis-

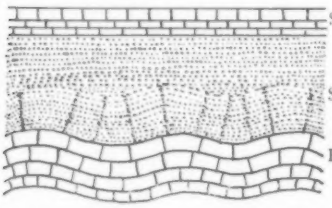


Fig. 4.—Showing the relationship of the Upper Stones River (S. R.) and lower Beekmantown (B.) Beds of Minnesota and the included St. Peter (St. P.) (Redrawn from Hall and Sardeson.)

[1] Compare Zittel, *Beiträge zur Geologie und Palaeontologie der lybischen Wüste.*

[2] Hall and Sardeson, *Bull. Geol. Soc. Amer.*, Vol. III., pp. 354, 355.

conformity, and the highest beds are thus wanting. In Center County, Pennsylvania, the upper beds appear to be completely represented. They are succeeded by 2,335 feet of dolomitic limestones, classed by Collie with the Beekmantown, but for reasons given elsewhere[1] referred by the author to the Chazy; and by 235 feet of limestones of Upper Stones River (Upper Chazy) age. The succession seems to be uninterrupted, placing this section in the region of non-emergence, while the others cited belong in that of emergence during late Beekmantown time. The section in central Pennsylvania does not, however, show the base of the Beekmantown, which is thus thicker than 2,500 feet (see Fig. 5). There seems no reason for doubting that the higher

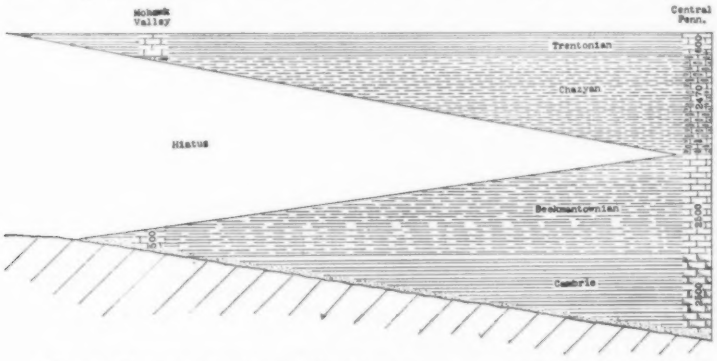


Fig. 5.—Diagram showing relationships between the Mokawk and Central Pennsylvania sections and the character of the overlaps and "off-laps," with the progressively decreasing hiatus.

beds of the Beekmantown were progressively deposited during the slow retreat of the sea, and that each higher member had, in general, a smaller areal distribution than the preceding one. On this view the successive members have the "off-lapping" arrangement of shingles, except that the earlier and lower formations are continuous beneath the higher ones. This is regressive overlap or "off-lap," and seems to supply the only rational explanation answering to the facts. To assume that the whole of the Beekmantown was deposited before retreat began, not only makes the negative diastrophic movement a cataclysmic one, where the positive movement was a very slow

[1] *Types of Sedimentary Overlap*, p. 619.

and regular one, but also necessitates the further assumption of an enormous erosion during the succeeding transgressive movements, which not only removed the greater part of several thousand feet of strata over the northern United States area, but also the whole of the extensive Canadian deposits of Beekmantown which must have reached far toward the Arctic regions, if the entire Beekmantown was deposited as a transgressional series. Aside from the fact that erosion would scarcely be very active during a positive diastrophic movement or transgression of the sea, it can hardly be assumed that such extensive erosion preceded the deposition of the St. Peter sandstone and the Chazy formation. Moreover, the intimate relation between the Lower St. Peter and the underlying Lower Beekmantown demands a close succession in deposition, the lower sand beds being probably deposited by the shoaling sea itself. If that is indeed the case, no higher dolomites of Beekmantown age than are now found ever existed in the Minnesota area.

West of the Rocky Mountains, the basal Uinta quartzite is chiefly if not wholly a continental deposit of pre-marine Cambric time, 12,000 feet or more in thickness. Upon this enormous basement series the eastward-transgressing Cambric sea laid down its progressively overlapping strata, the upper beds of the series being reworked during the progress. The transgressing sea apparently did not reach the region of the eastern Uintas, where the basal quartzite is succeeded by the Lodore shales. From these shales Powell reported Carboniferous (Mississippic?) fossils,[1] and he gives evidence of the existence of a disconformity between these shales and the basal sandstone. Weeks[2] identifies the Lodore with the Iron Creek shales of Berkey, which lie between the Uinta and the Ogden quartzites, and which Berkey correctly correlates with the Cambro-Ordovicic Ute limestone of the Wasatch. Weeks fails to recognize that, as Berkey has shown, the Ogden quartzite has united with the Uinta in the eastern section, the intervening shales having wedged out. The Lodore of the eastern Uintas thus lies above the Ogden horizon, and corresponds to a part of the overlapping Mississippic series (see Fig. 6).

The Lower Ordovicic retreat is shown in the western section by the

[1] *Geology of the Uinta Mountains.*

[2] *Bull. Geol. Soc. Amer.*, Vol. XVIII, pp. 435, 436.

appearance of the Ogden quartzite and conglomerate, which bears internal evidence of continental, chiefly river, origin; and to all appearance represents the sand and gravel wash which followed the retreating sea westward, and which was probably in large part derived from the basal Uinta quartzites, with which the Ogden seems to become confluent in the eastern Uintas.[1] This quartzite rests on higher beds in the western sections than in the eastern, thus showing the same relationship to the underlying series that is exhibited by the St. Peter sandstone. In the western Uintas it is underlain by 1,200 feet of shales, regarded as Cambric, though the highest beds may represent the Lower Ordovicic. In the Wasatch Mountains the Ute limestone, 2,000 feet thick, and of Cambro-Ordovicic age, lies between the Ogden and Uinta quartzites. In the Eureka section of central Nevada, the Pogonip limestone, 2,700 feet thick, underlies the Eureka quartzite, the westward continuation of the Ogden. The Pogonip represents, in its basal portion, the transition beds from the Upper Cambric, but corresponds mostly to the Beekmantown of eastern North America. Beneath it are 6,200 feet of fossiliferous shales and limestones of Cambric age. Here, as in the eastern region, succes-

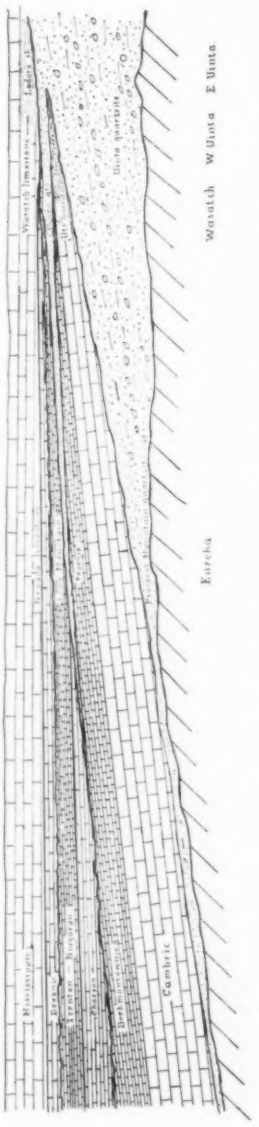


Fig. 6.—Diagram showing the relationships and overlaps of the Paleozoic strata west of the Rocky Mountains.

[1] Berkey, *Bull. Geol. Soc. Amer.*, Vol. XVI, pp. 517–30.

sively higher beds appear beneath the quartzite in the direction of the retreat, indicating continuous deposition during the slow regressive movement of the sea, this being checked as the localities successively emerged.

A widespread negative diastrophic movement is thus shown to have taken place over the whole of the North American continent, accompanied and followed by the spread of subaërial clastics over most of the area. At least 2,500 feet of calcareous strata were deposited in the non-emerging areas, and most of this constitutes the depositional equivalent of the retreatal movement (see map, Fig. 3).

The Beekmantown faunas.—The Beekmantown faunas are, so far, best known from the Lake Champlain region, the Mingen Islands, and the Newfoundland section. The Lake Champlain region, including the Phillipsburg section of the Canadian extension, has furnished a considerable number of species. Its distinctive character will be seen on consulting published lists.

The Pogonip limestone of Nevada contains mostly species unknown outside of this formation in the West, though a number of them have been referred by Walcott to eastern species, largely Trenton and Chazy types. In almost all such cases, however, the identification is provisional, and regarded by Walcott himself as doubtful. There is nothing in the character of the fauna which positively demands its reference to either the Chazy or Trenton, as has been done.

GRAPTOLITE FACIES OF THE BEEKMANTOWNIAN

In the Hudson and St. Lawrence valleys the Beekmantown is represented by the lower portion of the Hudson River shales, above the beds with *Dictyonema flabelliformis*. Some 340 feet of strata appears to be referable to this series, of which the lower 300 feet constitutes the first and second Deepkill zones, synchronous with the Upper Point Levis zone of Canada and the St. Anne zone of Newfoundland. Here the genera Chlonograptus, Goniograptus, Tetragraptus, and Phyllograptus (*P. anna*), with *Didymograptus bifidus*, characterize a succession of zones recognizable in various parts of the world. The upper forty feet of this series (third Deepkill zone)

is characterized by *Diplograptus dentatus* and *Cryptograptus antennarius*. This zone has been correlated by Ruedemann with the Chazy limestones of the Champlain region, but it probably is also referable to the Beekmantown, since most of its characteristic types occur in the Upper Arenig of Great Britain. The world-wide distribution of these graptolite faunas suggests that they were dispersed by strong currents sweeping through an open channel along the inner or western side of an Appalachian continent and its New England extension (Taconia). The fauna was most likely spread from Australia by strong currents passing up the west coast of South America and entering the Appalachian synclinal trough, along which it flowed northeastward to Newfoundland. Northwestward of this zone of mud-deposition we find the limestone of the Beekmantown grading down, by the addition of quartz grains, into the basal quartz sand, without intervening mud deposits (see map, Fig. 2).

With the progress of Beekmantown retreat the channel was closed, a land bridge connecting Taconia with Laurentia. Thus the mud deposition was checked and only a moderate thickness of Beekmantown strata of this type was formed. This represents, therefore, largely the lower part of the Beekmantown. As has been stated, it is probable that the Chazy is unrepresented by deposits of mud, the channel remaining closed until the end of that period, when it reopened through the progress of Chazy transgression, and the Normanskill beds, with a late Chazy (Lowville) and Black River graptolite fauna, were formed. In spite of some similarities, the *Diplograptus dentatus* and the *Coenograptus gracilis* zones are quite distinct, the important genera, Odontocaulus, Thamnograptus, Corynoides, Azygograptus, Leptograptus, Nemagraptus (Coenograptus), Dicellograptus, and Dicranograptus, appearing suddenly. In like manner, the characteristic Beekmantown genera, Dendrograptus, Goniograptus, Loganograptus, Dichograptus, Tetragraptus, Phyllograptus, and Didymograptus, continue through the third Deepkill zone, only the last of them extending into the Normanskill zone. Certain long-lived genera, Desmograptus, Diplograptus, Clonograptus, Climacograptus, and Cryptograptus, begin in the third Deepkill zone and extend through all or most of the remaining Ordovicic. Of the genera in common between the third Deepkill and the Normanskill,

Didymograptus is represented by three species,[1] all common in the Normanskill, and all distinct from those of the lower horizons, where eighteen species are recorded. Of the genera beginning in the third Deepkill, or Point Levis zone, Climacograptus has only one species in the lower zone, which is not known above that zone, while there are thirteen species, most of them abundant, in the Normanskill; Cryptograptus has one species in the lower and two others in the higher zone, common in each case; Desmograptus has two species in the lower and one in the higher, the latter rare; Diplograptus has four species in the lower and thirteen in the higher horizon, all distinct; while Clonograptus has two rare species in the lower and nine in the upper, mostly common. It is thus seen that there are no species in common between the two zones, and the most characteristic genera of each are unknown or rare in the other. On the other hand, six out of the twenty-four species listed by Ruedemann for the third Deepkill zone, or 25 per cent., occur also in one or both of the lower zones. Its relationship to that and distinctness from the Normanskill zone thus becomes evident. The forty feet of the third Deepkill zone probably represents the last deposits in an already shoaling and contracting channel before interruption took place, this break continuing to the end of Chazy time, when a new graptolite fauna came into existence.[2]

On the whole, the Beekmantown represents one of the large stratigraphic divisions of the Ordovicic of North America. Its fauna is essentially a unit, and although the succeeding Chazy fauna is in part, at least, derived from the Beekmantown, its distinctness is nevertheless marked. The Beekmantown corresponds to a great negative diastrophic movement, with the exception of the lower portion, and its thickness (2,500 feet where fully developed) shows that it represents fully one-third of the entire Ordovicic series, and presumably represents one-third of Ordovicic time. From this it follows that the Beekmantown alone represents the Lower Ordovicic in North America, the Middle Ordovicic beginning with Chazy deposition. The term *Beekmantownian* has therefore been proposed as the North American equivalent of Lower Ordovicic, while the

[1] Varieties are here classed as species.

[2] See Ruedemann, *Graptolites of New York*, Vols. I and II.

term Canadian becomes obsolete. The *Beekmantownian* corresponds essentially to the *Arenigian* of England and its continental equivalent.

B. THE MIDDLE ORDOVICIC OR CHAZYAN

In its maximum development, the Chazy shows nearly 2,500 feet of limestones, many portions of which are highly fossiliferous. An apparently complete development of this series, resting with conformity upon the Beekmantown, is described by Collie from Center County, Pennsylvania. Here 2,335 feet of dolomitic limestones, with fossils poorly preserved, succeeds the Upper Beekmantownian; and above this is 235 feet of fossiliferous limestones of Upper Stones River (Upper Chazy) age, succeeded in turn by the Black River. Sedimentation seems to have been continuous throughout, and this section may therefore be regarded as typical of the Mid-Ordovicic in its entirety. In southern Pennsylvania, Stose reports a disconformity and hiatus between the Beekmantown and Chazy (Stones River) limestones. The latter are from 800 to 1,000 feet thick, and are succeeded by the Chambersburg limestone (100 to 600 feet thick), which carries an Upper Chazy and Black River fauna. Continuous deposition seems to have obtained between the two series. In the Lake Champlain region, a hiatus also exists between the Beekmantown and Chazy, with the result that only about 900 feet of Chazy occurs in this region below the Black River beds. In western Newfoundland at least 2,000 feet of strata is referable to this series, the succession being conformable. Here, however, the upper limit of the Chazy is not known, the highest bed (P) being succeeded by continental sediments of much later age.

In the Arbuckle Mountains the hiatus between Beekmantown and Chazy is marked by a sandstone, and only the upper 2,000 feet of the Chazy (Simpson) is shown, followed by Black River. The Chazy is absent in the Mohawk Valley, except for a few feet of Lowville which lies disconformably upon the eroded surface of the Lower Beekmantown (Little Falls dolomite), and is conformably succeeded by the Black River. In the Black River Valley, at Watertown and northward, the sedimentation from Lowville to Black River is continuous and gradual. Cushing[1] finds in the Theresa quadrangle

[1] *Bull. Geol. Soc. Amer.*, Vol. XIX, pp. 155–76.

from 115 to 215 feet of strata beneath the Black River, and resting disconformably upon the Lower Beekmantown (Theresa formation), which, with its basal sandstone (called Potsdam by Cushing), has a maximum thickness of 140 feet. Cushing restricts the term Lowville to the upper 75 to 85 feet of pre-Black River strata, separating the lower part, on paleontologic grounds, as the Pamelia limestone. At Lowville and elsewhere this series overlaps the Beekmantown, resting with a basal sandstone upon the crystallines. The Pamelia fauna is an Upper Stones River fauna, according to Ulrich, while the fauna of the Lowville is compared with that of the Upper Chazy.[1]

In the Canadian region, only Upper Chazy (Lowville and possibly the Pamelia equivalent) is present. In a number of localities it rests directly upon the pre-Cambrics, generally with a basal sandstone (St. Mary's sandstone). In some cases, however, lower beds (Beekmantown, with basal sands) have been reported. In Minnesota and Wisconsin the Upper Chazy is called Stones River, though it represents only the upper part of the Stones River formation of Safford's Tennessee section where the thickness is 360 feet. The Minnesota beds are 32 feet thick and are probably the exact equivalent of the Lowville of New York, though the fauna is stated to be more like that of the Pamelia. The relation of these beds to the underlying St. Peter sandstone is significant, since the contact is perfectly conformable and gradational. Moreover, Stones River fossils (*Hormotoma gracilis*, *Lophospira perangulata*, etc.) are found in some of the upper beds of the St. Peter, showing that with the advent of the Chazy sea, the sand dunes of the St. Peter desert were incorporated as basal sands in the overlying formation. This meant, of course, a slight reworking of the sands by the encroaching sea. That this reworking did not reach to the bottom of the St. Peter, at least not in all cases, is shown by the persistence of the folds and faults in the lower beds, whereas they are absent in the upper (see Fig. 4). A comparison of sections shows that in general lower beds of Chazy age appear progressively above the St. Peter as we proceed southward and eastward. The relationship of these beds to the St. Peter has not been discussed in detail, but it is certain that in some localities, at least, the gradation observed in Minnesota obtains. The relation-

[1] See Cushing, *loc. cit.*

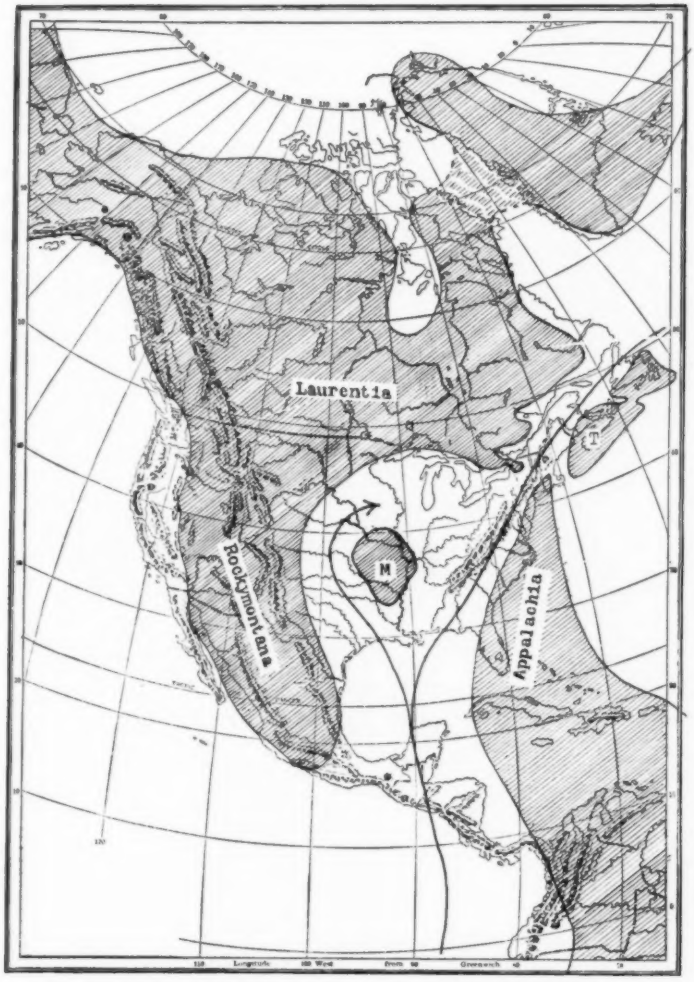


Fig. 7.—Paleogeographic map at the end of Chazy time and the probable currents. M, Ozark Island, the remains of Mississippia T., Taconic Island.

ship is, accordingly, that of a progressively overlapping transgressional series to its basal bed, and this is the interpretation favored by all the sections. The Chazy was, in fact, characterized by a transgressive or positive diastrophic movement throughout (barring possible minor oscillations), and therefore only the higher beds are found in the region of late submergence. The thickness of the formation beneath the Black River, forms in general a reliable guide to the division of the Chazy represented, though of course there may be discovered some minor disconformities which would vitiate detailed correlations made on this basis in a given region.

No unquestionable Chazy beds have been reported from the Pacific region, where the Trentonian seems to rest directly upon the Eureka quartzite in Nevada, and either Siluric or Devonic succeeds the Ogden quartzite of the Wasatch, with Mississippic beds succeeding the same in the Uintas. The west coast transgression was, therefore, less pronounced, the Nevada region remaining still uncovered at the end of Chazy time (see map, Fig. 7). If Chazy beds occur in the West, they must be sought for in western Nevada and California. It is, of course, impossible to say how much has been removed by late Ordovicic erosion. It is not improbable that the Chazy extended east of Eureka, Nev., but was removed again in Upper Ordovicic time.

The Chazy fauna.—At the beginning of Chazy time, the Champlain gulf was entirely distinct from the Appalachian gulf, there being a land connection between the Laurentio-Mississippian continent and the united Appalachia and Taconia, or Ancient New England continent (see map, Fig. 3). The faunas were thus to a large extent distinct, representing, in fact, the Atlantic and the southern type. The southern type was, in general, the Stones River type of fauna; the character of which may be seen by consulting published lists. The Atlantic type is seen in the fauna of the Champlain basin, which admits of a threefold division, a lower (Div. A) with *Orthis costalis*; a middle (Div. B) with *Maclurea magna*; and an upper (Div. C) with *Camarotoechia plena*.

That these two types of faunas were not wholly distinct in middle and later Chazy time is shown by the occurrence of true Champlain species of Mid-Chazy age, including *Maclurea magna* in the middle

portion of the "Stones River beds" of southern Pennsylvania; and of Upper Chazy species, including *Camarotoechia plena*, in the Chambersburg limestone of the same region. Whether this implies an Appalachian extension of the Champlain gulf or a connection with the Atlantic in the southern part of North America must be determined by further detailed study. It is probably true, however, that the open passage along the west border of Appalachia and Taconia, through which the mud-bearing currents swept in early Beekmantown time, and which formed the route of dispersal for the graptolite fauna of that age, was not re-established until late Chazy or Black River time. This accounts for the slight development of the graptolite-bearing shales referable to the Chazy in the Hudson and Levis series. The disconformity which represents this interruption would probably be difficult to trace in strata of such similar lithic characters.

THE BLACK RIVER FORMATION

This formation is widespread, having been traced by its fauna from the Champlain Valley to the upper Mississippi and southward to Oklahoma and the Appalachians. Over this area it forms an excellent datum plane from which correlation of overlying and underlying formations becomes possible. Its thickness is never very great; it is only 7 feet in the type region, at Watertown, N. Y., 50–60 feet in Minnesota, less than 100 feet in Oklahoma, 90 feet in southern Pennsylvania, and 70 feet in the Champlain Valley. Faunally, it represents a transition between the Chazy and Trenton, as will be seen by consulting published lists. Its classification with either the Chazy or the Trenton is therefore permissible. Since the formation represents the unchecked continuance of the transgressive movement initiated at the opening of Chazy time, its classification with that series of strata as Mid-Ordovicic is perhaps most desirable.

THE NORMANSKILL BEDS AND FAUNA

The Normanskill shales are generally regarded as representing the shale facies of the Lower or Middle Trenton. Ruedemann, in his recently published monograph parallels them with the *Lowville*, *Black River*, and *Lower Trenton*.[1] In Rysedorf Hill, the shale includes a conglomerate, the pebbles of which, regarded as nearly syn-

[1] *Graptolites of New York*, Part II.

chronous with the shale, carry a Lowville–Black River–Lower Trenton fauna, with some elements (*Christiania trentonensis, Ampyx hastatus*, Remopleurides, Sphaerocoryphe, Cybele, etc.) suggesting a geographic connection with the European sea of that time. The typical graptolite fauna of the Normanskill includes more than 60 species in all, though the widely distributed forms are much fewer. The more constant and characteristic species comprise: (1) *Coenograptus* (*Nemagraptus*) *gracilis;* (2) *Dicellograptus sextans;* (3) *D. divaricatus;* (4) *Dicranograptus furcatus;* (5) *D. ramosus;* (6) *Diplograptus foliaceous;* (7) *D. angustifolius;* (8) *Climacograptus parvus;* and (9) *C. bicornis.* Of this list, Nos. 1, 2, 4, and 8 are the most characteristic index fossils of this zone. *Didymograptus sagitticaulis*, Gurley, and *Climacograptus scharenbergii*, Lapw, may also be mentioned as characteristic though less widely distributed forms.

Besides the numerous localities along the Hudson and St. Lawrence valleys, this fauna is known from Maine and New Brunswick. In the Appalachian region it is definitely known only from New Jersey and from Bebb County, Alabama; it is also doubtfully identified from western Virginia and eastern Tennessee. It has been found in Arkansas and the Ouachita Mountains of Oklahoma; in southern Nevada (Belmont and Letson peak); and in the Kicking Horse Pass of the Rocky Mountains of British Columbia. It is also known from New South Wales and Victoria in Australia; and from southern Scotland, Scania, and France.

The distribution of this fauna is such as to suggest an eastern and a western land mass (Appalachia and Rockymontana) of low relief, with currents of the Gulf Stream type sweeping along their inner borders and distributing the graptolites, which became entombed in the muds that accumulated in these channels of moderate depth. The division of what was probably a single great current, sweeping north along the South American coast, and carrying the graptolites from Australia, was probably due to the existence of an Ozarkian island or Archipelago, along the borders of which, as in Arkansas and Oklahoma, were deposited some of these black muds. One arm of the divided current swept along the east coast of Rockymontana to the Arctic Sea of Alaska; the other along the west coast of Appalachia, past a Newfoundland island, and across the North Atlantic

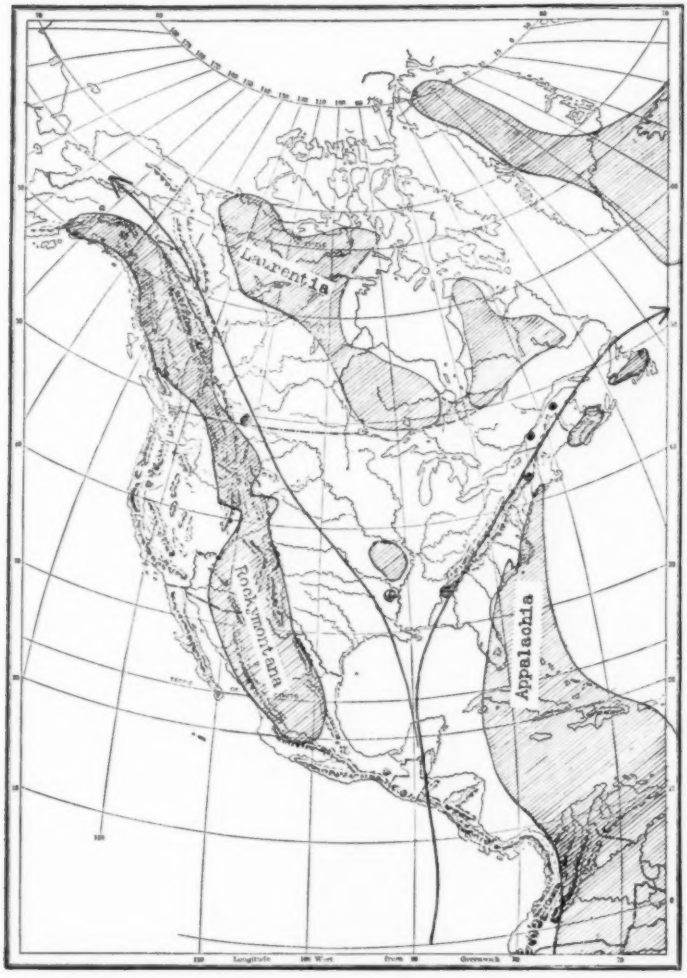


Fig. 8.—Paleogeographic map at the end of Trenton time, showing second maximum transgression in the Ordovicic. The currents are indicated for Black River time. ⊕ indicates distribution of B. Normanskill graptolites.

to northern Europe (see Fig. 8). Within the protected interior sea, limestones (Upper Stones River and Black River) accumulated. Limestones accumulated also along the shores of Laurentia (Canadian shield) in the St. Lawrence channel, the two types of sediment and faunas thus occurring side by side. There is no need for postulating a dividing ridge in this channel, for the faunas and sedimentation would remain different as long as the different physical conditions persisted.

In Great Britain and elsewhere in Europe the zone of *Coenograptus gracilis* forms the summit of the Middle Ordovicic. The next succeeding zone (Hartfell shales of the Moffat district) is of Upper Ordovicic or Caradocian age. This begins with the zone of *Dicranograptus clingani*, which in North America is represented by the Magog shales or *Diplograptus amplexicaulis* zone, which succeeds the Normanskill beds.

The diastrophic movement, which in North America resulted in the emergence of most of the continent at the end of Lower Ordovicic time, was likewise marked, though to a less extent, in Europe. Lamansky has recently shown[1] that between Baltic Port and the banks of the river Volkov, the Lower Ordovicic beds (Etage B) show the progressive off-lapping structure characteristic of a retreatal or beveled-off series of sediments. At Baltic Port only the *Megalaspis planilimbata* zone (BIIα) occurs. Farther east, at Reval, the higher *Asaphus bröggeri* zone (BIIβ) and a part of the *Asaphus lepidurus* zone (BIIγ) have appeared. In the extreme east of the gouvernement of St. Petersburg, on the Volkov, the whole of BIIγ, and the *Asaphus expansus* zone (BIIIα) have come in above the others. The line of disconformity and erosion is marked by slight irregularities, by glauconite, iron oxide, and phosphate concretions, rarely by siliceous sediments. Above the erosion plane, the beds of BIIIβ and BIIIγ (zones with *Asaphus raniceps* and *Asaphus eichwaldi*) show progressive overlapping, the latter being represented only by clastic material at Baltic Port. Above these lies the Echinosphaerites limestone C, which shows continued westward overlapping.

[1] Lamansky, W., "Die ältesten silurischen Schichten Russlands," *Mém. du Comité Geol.*, N. S., Livr. XX, 1905.

The regressional movement here indicated appears to coincide with that of North America, but the transgressive movement seems to have begun somewhat earlier, unless the Lower Ordovicic is regarded as ending with the *Asaphus expansus* zone.

C. THE UPPER ORDOVICIC OR TRENTONIAN

Most current classifications of the Ordovicic formations of North America unite the Black River and Trenton limestones under Clarke and Schuchert's term Mohawkian, which is made synonymous with Middle Ordovicic. As we have seen, the Middle Ordovicic is represented by the Chazyan, which in its maximum development includes some 2,500 feet of limestone strata, and is therefore comparable in

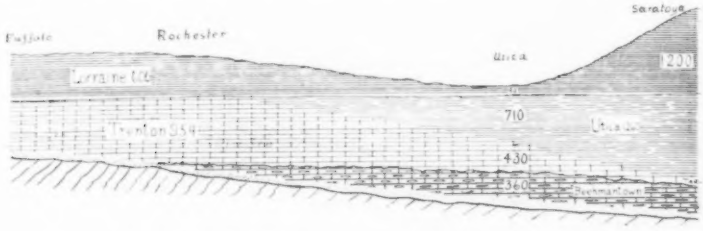


Fig. 9.—Diagram showing the relationships of the Ordovicic strata of New York, between Saratoga and Buffalo.

magnitude and, inferentially, in time value, to the Beekmantownian or Lower Ordovicic. The fauna of the Chazyan is, moreover, distinct from both preceding and succeeding faunas, and the natural dividing-line between the Middle and the Upper Ordovicic is shown, by paleontologic, stratigraphic, and diastrophic reasons, to be within or above the Black River horizon; a division coinciding with that made in the European series. The Trenton limestone of America is not a stratigraphic unit, but, as has been repeatedly demonstrated by Ruedemann and noted by many observers, it is the limestone phase of a series which elsewhere is in part or mostly represented by Utica shale. In the Mohawk Valley the dividing-line between Utica and Trenton is a line constantly rising to the west, the transition being in some cases abrupt, though probably in most cases it is gradual. Ruedemann has pointed out the progressive increase in thickness

westward of the limestone, and corresponding decrease in the shale; the former increasing from 40 feet at Saratoga to 430 feet at Utica, and to 954 feet at Rochester, while the latter decreases from 1,260 feet to 710 feet to probably zero over the same localities (Fig. 9). In the South Mountain region of southern Pennsylvania, the Chambersburg limestone of Stones River, Black River, and Lower Trenton age is succeeded by 1,000 feet of gray fossiliferous and dark bituminous shales, with intercalated limestone members in the basal portion which carry a Lower Trenton fauna. The shales contain *Leptobolus insignis*, *Triarthrus becki*, and Utica graptolites, and are succeeded by a sandstone with the fauna of the Eden beds of the Cincinnati region, formerly identified as Utica, but now regarded as younger than that formation. In central Pennsylvania, some 600 feet of Trenton succeeds to Black River, and is followed by 650 feet of Utica shale. In this zone also we have some typical Trenton species, such as *Dalmanella testudinaria*, *Isoteles platycephalus*, etc., associated with *Triarthrus becki* and other Utica species. The various sections clearly show that along the western border of the Appalachians, dark graptolite shales continued to form in Upper Ordovicic time, while westward from this the Trenton limestone represents the calcareous phase of the Utica-Trenton series (see map, Fig. 8).

THE TRENTON-UTICA GRAPTOLITE FAUNAS

The Normanskill fauna is succeeded by that of the Magog shales or zone of *Diplograptus amplexicaulis*—the upper Dicellograptus zone of Gurley. This represents, according to Lapworth, highest Llandeilo or lowest Caradoc, and forms a transition to the true Utica fauna. Many of its species are characteristic of the Hartfell shales (Caradocian) of southern Scotland, though others are equally characteristic of the Normanskill and Glenkiln shales. Ruedemann regards this fauna as a relict of the preceding one.

> The Didymograptidae have vanished entirely, and the Dicranograptidae almost; only the long range forms, *Dicranograptus ramosus* and *nicholsoni*, are still observed, and the Diplograptidae . . . . hold now almost entirely the field, with the genera Diplograptus, Climacograptus, and Cryptograptus.[1]

The fauna is best developed near Quebec and at the north end of Lake Memphremagog, only fragmentary representation occurring

[1] *Op. cit.*, II, 30.

in New York. The fauna is rapidly changing, the true Upper Ordovicic faunas are appearing, and soon the typical Utica fauna, with *Glossograptus quadrimucronatus*, *Climacograptus typicalis*, *Corynoides curtus*, and, less frequently, *Leptograptus flaccidus*, *Dicranograptus nicholsoni*, and *Climacograptus putillus* is established. The association of typical Utica graptolites with characteristic Trenton limestone fossils, as *Trocholites ammonius*, *Cameroceras proteiforme*, and *Schizocrania filosa*, bears on the previously discussed question of the synchroneity of the Utica and Trenton.

Climacograptus typicalis, the typical Utica species, is reported by Winchell and Ulrich from the Fusispira and Nematopora beds of the middle Galena of Minnesota. Since the Galena of that section follows directly upon the Black River, this occurrence is only a short distance above the base of the Trenton, which is thus indicated to be the western limestone equivalent of the Utica shale of the east. As already noted Ruedemann has cited abundant evidence of the gradual westward extension of the successively higher zones of the Utica, and the replacement of the limestone phase (Trenton) by them. The Galena-Trenton limestone of the Lake Winnepeg region contains *Dictyonema canadense* (Whiteaves), *Thamnograptus affinis* (Whiteaves), and the typical Utica species, *Climacograptus typicalis* (Hall). Whiteaves concludes that the Galena-Trenton of Lake Winnepeg "most probably represents the whole of the Utica and Trenton formations, inclusive of the Galena."[1]

THE CINCINNATI GROUP

This is the upper calcareous phase of the latest Upper Ordovicic, and comprises, in ascending order, the Eden, Maysville, and Richmond. The Eden was formerly correlated with the Utica, but the underlying Trenton mainly represents that formation. The Eden is in part equivalent to the Frankfort shales, though the occurrence of *Climacograptus typicalis* in the Eden strata would favor its former correlation with the Utica. The Maysville represents later Lorraine as developed in New York, though the fauna, being that of a calcareous facies, is markedly different.

Ulrich has reported a disconformity at the base of the Eden, in the Cincinnati section, but this, if it exists, does not appear to be

[1] Quoted by Ruedemann, *op. cit.*, II, 28

of great importance. It certainly does not represent Utica shale. There is, however, a marked and widespread disconformity between the Lower and Upper Trentonian, the late Richmond resting on Trenton or even earlier beds. This is observed throughout the Rocky Mountain area, the upper Mississippi region, and to a less extent in other sections. It signifies a retreat of the sea, probably at the end of Trenton time, and a return during late Richmond time.

THE TRENTON–CINCINNATI FAUNAS

While on the whole the faunas of the Trenton limestone and of each one of the three divisions of the Cincinnati group are sufficiently distinct, so that it is not difficult to recognize the exact horizon of each by a careful analysis of the fauna, there is, nevertheless, a unity in these faunas, which shows their unmistakable relationship to one another and their distinctness from the preceding faunas. It is this broad similarity of faunas, together with the distinctness from the preceding faunas, the intimate relation of the limestone to the Utica shale which it replaces, and the moderate thickness of the formation in its best development, as compared with that of the Chazy and Beekmantown, that has led me to place the Trenton limestone in the Upper Ordovicic. In England, the Upper Ordovicic or Caradocian (Bala) is characterized by the same faunal elements which here appear for the first time. The more common species characterizing the Upper Ordovicic from the Trenton up, and occurring in most if not all of its beds, include *Rafinesquina alternata, Plectambonites sericea, Dinorthis subquadrata, Plectorthis plicatella, Dalmanella testudinaria, Platystrophia biforata; Protowarthia cancellata, Liospira micula, Clathrospira subconica, Trochonema umbilicatum, Cameroceras proteiforme, Calymmene callicephala, Isoteles gigas, I. maximus,* and *Ceraurus pleurexanthemus.*

Some of these species begin in the Black River or even in the Upper Stones River, but they are most characteristic of the higher horizons.

THE CONTINENTAL PHASE OF UPPER ORDOVICIC TIME

The later epochs of Upper Ordovicic time were characterized by continental or non-marine sedimentation in the Appalachian region. The earliest of these is the conglomeratic and quartz-sand

series found directly overlying the fossiliferous marine Ordovicic of southern Pennsylvania, and generally classed by Pennsylvania geologists as "Oneida." This is a gray to white, rarely red, conglomerate and quartz sandstone with rounded quartz pebbles and characterized by extensive cross-bedding. Its maximum thickness today is in Bald Eagle Mountain, near Tyrone City, Blair County, Pennsylvania, after which locality I originally named it.[1] This name, however, was preoccupied, and the formation under consideration is therefore called the Bald Eagle conglomerate, this ridge being due to the resistant character of this and the succeeding formation. At Tyrone the thickness is 1,319 feet, while thirty miles to the northeast, at the Bellefonte Gap, through the same ridge, the thickness is only 550 feet, and the formation is divisible into a lower hard gray sandstone without pebbles, 170 feet thick, and an upper greenish-gray somewhat ochery and micaceous sandstone with intercalated greenish shales. One hundred and sixty miles northwest from Tyrone, at Buffalo, this formation (Oswego sandstone) is 75 feet thick. It is here a white quartzite lying below the red Queenston shales, and represents only the upper layers of the gradually spreading fan of clastic sediments. In central New York the Oswego is 185 feet thick at the falls of the Salmon River. It there succeeds the Lorraine beds with perfect conformity, some Lorraine fossils extending into the lower Oswego.

There can be little doubt that these beds represent the northern and western attenuated upper beds of the Bald Eagle conglomerate of Pennsylvania, unless indeed they belong to one or more distinct fans with a source in the north.

The character of the rock, its cross-bedding, and absence of fossils indicate continental origin, and this is also shown by the nature of the overlap, which is that characteristic of river deposits. The intimate relationship between the Lorraine and the highest bed (Oswego sandstone) of this formation, indicates that the age of this formation is Lorraine. The Bald Eagle conglomerate is everywhere succeeded by the red shales and sandstones of the Juniata formation. In southern Pennsylvania this overlaps the preceding formation and rests directly upon the Eden sandstone. The forma-

[1] *Science*, N. S., Vol. XXIX, p. 355.

tion here contains remnants of the Lorraine fauna with *Byssomichia radiata* and other types. These beds are clearly the lower Juniata, for the base of the series is seen in contact with the Bald Eagle conglomerate not far away. The maximum thickness of the Juniata in central Pennsylvania is from 1,000 to 1,200 feet. On the Niagara, the corresponding Queenston shale is 1,100 feet thick, and it thins away almost wholly before reaching Michigan, where only a few red beds mark the summit of the Ordovicic.

The Juniata has all the characters of deposits in arid regions. The total absence of fossils, except where, at the beginning, a lagoon extended north into Pennsylvania, is a striking feature. That fossils could be preserved in the formation is proved by the occurrence

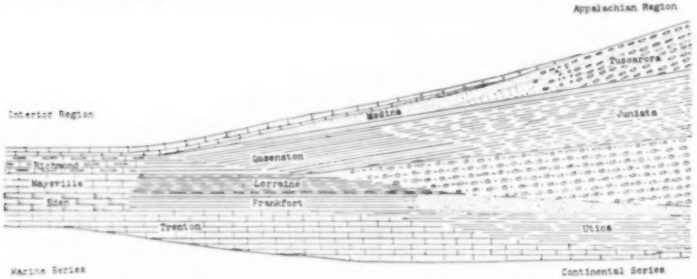


Fig. 10.—Diagram showing relationships of marine and continental upper Ordovicic and lower Siluric strata. The conglomerate beneath the Juniata is the Bald Eagle, and beneath it is the Eden sandstone.

of Lorraine species in the basal beds. Their absence from the others must then be taken as indicating that none were inclosed in the strata. This absence of fossils, together with the character of the beds, their red color, frequent mudcracks, and numerous clay slugs or "Thongallen" in the sands, and the aeolian cross-bedding, all point to a continental origin, under conditions of semiaridity and tropical climate. That the Juniata and Queenston beds are equivalent, and were formed under the same physical conditions, cannot be doubted. Their correspondence in thickness indicates an almost complete equivalency. They may, however, have distinct sources, one in the southeast and the other in the north. In western New York the Queenston shales are succeeded by the true Medina sandstones and green shales, which are partly fossiliferous, carrying a true

Niagaran fauna. This fixes the age of the Queenston and Juniata as Richmond, so far as their major portion is concerned; though, as already noted, the lower part must be considered as Lorraine (see Fig. 10).

In eastern Tennessee a second deposit of red sands of this period forms the Bays sandstone. This is from 1,100 to 1,300 feet thick in its maximum development near Loudon, but thins away by overlap in all directions. In some localities, as at Walker Mountain, it is fossiliferous, carrying the late Lorraine fauna with *Byssonychia radiata*, *Modiolopsis modiolaris*, etc. Wherever the contact with the underlying Sevier shale is exposed, it is seen to be a gradational one, the fossils extending part way up into the red beds. The basal white bed, comparable to the Bald Eagle conglomerate, if it ever existed here, was overlapped by the Bays, the portion east of the overlapping edge having been removed by erosion. The Bays may be regarded as an independent fan, or group of fans, of red sedimentation with a distinct center of supply.

The correlation of this series of continental sediments with the contraction of the sea known to have occurred in Upper Ordovicic time has not yet been attempted. It is not improbable that the initial uplift of the land which caused the retreat of the sea, also initiated the strong river-activities which resulted in the formation of the Bald Eagle conglomerate and sandstone. This probably corresponded to the period of folding of the Ordovicic and earlier strata in New England and northward. If that is the case, the emergence was probably post-Trenton, falling in early Lorraine (Frankfort or Eden) time and extending toward the end of Lorraine time. The period of red sedimentation in the east may have coincided with the period of erosion in the upper Mississippi and Rocky Mountain areas, and deposition of the Richmond in the narrow interior basins. The late Richmond expansion may coincide with the climatic change indicated by renewed river deposits of white quartzose material.

D. THE LOWER SILURIC OR NIAGARAN

The following divisions of the New York Niagaran are in common use as the North American standard: Guelph, Lockport, Rochester Clinton.

The Clinton of the best known section, that of western New York, begins with the true or Upper Medina, which, along the Niagara River, admits of a number of subdivisions, which are, however, of only local significance.[1] The total thickness is nearly 125 feet, with 25 feet of white quartzose sandstone (Whirlpool sandstone) at the base, and about 8 feet of a similar sandstone at the top. The middle series consists of red sandstones and green and gray sandstones and shales. The red sandstones generally show aeolian cross-bedding and appear to have accumulated above water. The green sandstones and shales are fossiliferous. The white Whirlpool sandstone exhibits beach features,[2] and probably marks the advance of the sea, though it is likely that the sand was originally dune sand, as suggested by A. W. G. Wilson.

The fossils are generally most abundant in the shales and thin-bedded sandstones. The heavy-bedded sands are either free from fossils or have only scattered shells of Lingulae. At Lockport and elsewhere some layers are crowded with gastropod shells. The characteristic fossil, *Arthrophycus harlani* is everywhere in New York restricted to the upper beds just below the upper white sandstone.

The fossils so far obtained from the Medina are: *Arthrophycus harlani* Conr.; *A.* sp.; *Daedalus* several species; *Scolithes verticalis* Hall; *Dictyolithes beckii* (Conr.); "*Fucoides*" *aurijormis* and "*F.*" *heterophyllus; Holopea fragilis* Hall; *Lingula cuneta* Conr.; *Whitfield-ella oblata; Camarotoechia* sp.; *Uncinulus stricklandi* (Sowerby); *Plect-orthis medinaensis* sp. nov.; *Rhipidomella* sp.; *Pentamerus* sp.; *Modiolopsis orthonota; M. primigenius; Pterinea cf. emacerata; Pleurotomaria pervetusta* Conr.; *P. littorea* Hall; *Holopea* (?) *conridea; Bucanopsis trilobatus* (Conr.); *Oncoceras gibbosum; Orthoceras* sp.; *O. multiseptum* Hall; *Ascidaspis* sp.; *Dalmanites* sp.; *Isochilina cylindrica* Hall.

This is a Lower Siluric fauna, and favors more especially the Clinton and Rochester faunas. It is so far known only from western New York, with the exception of *Arthrophycus harlani*, which is widely distributed. In western New York this species occurs at the top of a heavy-bedded unfossiliferous sandstone with an aeolian type

[1] See *Bull. 45, New York State Museum*, pp. 88–95.

[2] Fairchild, H. L., *Amer. Geol.*, Vol. XXVIII, 1909.

of cross-bedding; and just below the upper white quartzite. In east-central New York it is found at the base of the Oneida conglomerate, which is the approximate equivalent of the upper white sandstone of Niagara. In the Appalachians, it is found mostly in the upper part of the Tuscarora and Clinch sandstones, the stratigraphic equivalent of the Medina. Sarle[1] has recently interpreted this structure as due to worm borings. So far as I have observed in the field, the raised ridges of this fossil always occur on the under side of the sandstone layers, representing, therefore, the relief molds of grooves generally formed in the clays beneath. These grooves had a median ridge and a regular succession of transverse ridges separated by broad concave grooves. A similar structure, known as Climatichnites trails, but of a much broader type, occurs in the Potsdam sandstone of New York. Woodworth[2] has suggested that it represents the trail of an animal comparable to some extent to modern Chiton.

There are no known remains of organisms in the Medina or Clinton capable of making such an impression, and the organism which made it either had no parts capable of preservation or else it was a terrestrial type frequenting the shores and sandy wastes, where it left its trail in the mud, but not its remains, just as the Triassic Dinosaurs left their footprints but seldom their skeletons.

The Tuscarora has a thickness of 820 feet in Logan's Gap, Jack's Mountain, Mifflin County, Pennsylvania, but thins perceptibly westward and southward, being 400 to 500 feet thick in Bald Eagle Mountain and 287 feet in Wells Mountain and the Pennsylvania-Maryland line. This thinning appears to be due to failure of the lower beds, showing a true case of non-marine progressive overlap. In New York, the upper part is represented by the true Medina, which has a thickness of 125 feet, and begins and ends with a pure white quartz sandstone. More strictly speaking, the upper white sandstone alone represents the true Tuscarora, but the lower beds, still partly red, and the shales, probably are the equivalent of the lower reddish sandstones and greenish shales underlying the true white Tuscarora, and sometimes referred to the Upper Juniata. The Oneida conglomerate of central New York, 40 feet thick, is likewise

[1] *Rochester Acad. of Sci. Proc.*, 1906, No. 4, p. 203.

[2] New York State Pal. Rep., 1907, *Bull. New York State Museum, No. 69*, p. 959.

the representative of the upper part of Tuscarora, though it may have had a more local origin.

All of these beds, including the basal white Bald Eagle formation, belong to the much-washed and reworked type of continental sediments, in which concentration of the indestructible quartz had been brought about by long exposure, resulting in the decomposition of all the other minerals, and the removal of the resultant clay and dust by wind and running water.

The Clinton shales succeed the Oneida conglomerate in Oneida and Herkimer counties, New York, and the Upper Medina quartzite in western New York. In the southern Appalachians, the series is largely composed of sandstones (Rockwood), highly impregnated with iron, and often containing beds of workable iron. It is generally succeeded by late Siluric (Monroan) or by Helderbergian or later beds, there being a pronounced disconformity at the summit of the Rockwood throughout. That part of the series in Virginia is of continental origin is indicated by the general character of the rocks, but marine intercalations are not uncommon. In some cases in eastern Tennessee the iron ore itself is fossiliferous, having replaced a marine limestone. In such cases the bulk of the formation is shale. In no case is the original thickness preserved since the formation is everywhere bounded above by an erosion plane. In northern Virginia today the thickness is 750 feet (Piedmont folio), and not over 400 feet in southern Virginia. In southern Tennessee and northern Georgia it is from 1,100 to 1,600 feet thick, decreasing westward and northward. With our present knowledge of the formations, it is safe to say that the eastern sandy phase represents near-shore deposits, if not actually continental conditions, formed probably at the embouchures of several Appalachian rivers; and that westward these deltas merged gradually into true marine deposits, mainly sands and clays, with some limestones intercalated. That the Rockwood represents more than the Clinton of New York cannot be questioned. Where the series is developed in its totality, it probably represents the entire Niagaran, if not a part of the Salinan as well. Along the Alleghany front, fossiliferous shales and iron ores represent this series, with a thickness of not less than 1,000 feet, on the western branch of the Susquehanna. The lower series, 700 feet thick, consists mainly of

fissile shales, including an iron sandstone, and with Buthotrephis in the upper part. This is succeeded by 110 feet of calcareous fossiliferous shales; and this by 230 feet of fossiliferous shales and limestones with a Niagaran fauna. Above this follows 350 feet of red shales, probably representing the Upper Salina, and separated by a hiatus from the fossiliferous Niagaran shales.

In eastern New York, at Swift's Creek, the type locality for the Clinton, this formation is 226 feet thick and is followed by 5 feet of Niagaran and then by the red shales of the Upper Salina. On the Niagara River the Clinton shale with the two succeeding limestones has a total thickness of 32 feet, followed by 68 feet of Rochester shale. The total of the Niagaran, including the Guelph, is from 270 to 325 feet, as shown by borings. This is followed by Lower Salinan. In the Rochester region the Clinton has a thickness of 80 feet, including the Irondiquoit or upper limestone (17 feet), which Chadwick refers to the Rochester. The eastward thinning of the Upper Niagaran beds indicates either that these beds were eroded before the deposition of the red shales, probably during the Shawangunk epoch (see beyond); or that the Rochester-Lockport of the West is in part represented by Upper Clinton in the East. The Guelph element may never have extended to the Clinton type region, which may have been above water and so subject to erosion.

The most typical section of the North American Lower Siluric or Niagaran is found in Wisconsin, where the series exceeds 700 feet in thickness and is wholly calcareous. At the base of the series, however, in a few localities, as at Iron Ridge, occurs a remarkable iron ore, composed of flat lentils of varying size and heaped together in a mass strongly suggestive of dune history. This idea is borne out by the position of these pellets, which are not laid flat, as would be the case if they were deposited by water, but are placed in all positions. Cross-bedding and irregular wedging-out of layers and a rapid thinning away of the entire mass, further suggest such an origin. There are no fossils in the ore, and it rests upon an uneven surface of the Upper Ordovicic, with a layer of highly polished clay pebbles marking its base. The interpretation of this formation that I am at present able to advance is that of a dune of calcareous pellets of concretionary or phytogenetic origin, similar to the oölite dunes of Great Salt

Lake and other regions; and that these dunes were subsequently altered, by replacement, to iron ore.

The series of limestones overlying this basal bed, or resting directly upon the Ordovicic, is for the most part richly fossiliferous. Some of the beds, as the Racine and the Coral Beds, are characterized by reefs of Stromatoporoids and other corals, widely distributed and connected by more or less barren lime sands (calcarenytes) which resulted from the erosion of the reefs. Some beds are of shallow-water origin and bear the marks of periods of exposure, resulting in the formation of mud cracks, etc. The fauna is more or less uniform throughout, and the series represents continuous deposition, recording only minor oscillatory movements. Southward we find these beds extending through northern Illinois, Indiana, and Ohio, with a more or less uniform fauna, while further south, in the Cincinnati and western Tennessee regions, part of the limestones is replaced by shales and new faunal elements appear.

The typical Niagaran fauna.—This is to be found in the strata of the Wisconsin section and in their continuations in northern Illinois, Indiana, Michigan, and Ohio. It is an exceedingly rich fauna, and, as Weller has ably demonstrated, has many elements in common with the Mid-European Siluric. The Stromatoporoids abounded on the reefs of the Coral Beds and the Racine. They have not been much differentiated in Wisconsin, but from other sections, especially Canada and Ohio, a considerable number of genera and species have been recognized. Corals abound, especially Halysites and Favosites, while Bryozoa are most common in the shales of New York and the southern area, Fistulypora making extensive reefs in western New York. The brachiopods, except the large Pentamerus, are likewise more characteristic of the shales. Crinoids, Cystoids, and Trilobites appear to be most common in the limestones of the interior.

The Guelph fauna.—This fauna demands a special notice, because it is so distinct in its eastern manifestations. The peculiar aspect of the fauna is produced by the great Trimerelloid brachiopods (*Trimerella grandis*, *T. ohioensis*, *Monomorella prisca*, etc.); the peculiar corals Pycnostylus; the large pelecypod *Megalomus canadensis;* the gastropods *Pycnomphalus solarioides;* and the genera

Euomphalopteris, Hormotoma, and Coelidium, together with various species of Eotomaria and other Pleurotomarioids, and the remarkable *Trematonotus alpheus*. This represents a new invasion of the interior sea, probably from the rich fauna of northern Europe. In North America the physical conditions accompanying this spread of the fauna appear to have been shoaling of the water and inclosure and restriction of the interior sea. The fauna appears as early as the lower Coral Bed in Wisconsin, while the Guelph element of the Racine fauna is very marked. *Trimerella grandis*, *Megalomus canadensis*, *Pycnomphalus solariodes*, *Coelidium macrospira*, and *Sphaeradoceras desplainense* are among the species which occur in association with the rich Racine fauna. Many of the typical corals, brachiopods, and other types continue into the Guelph in Wisconsin, the fauna not differing markedly from the Racine. In New York Clarke and Ruedemann have found the Guelph fauna intercalated between the normal manifestations of the Niagaran coral fauna (Lockport), and it appears that in the Canadian type region alone does it occur in its purity.

THE ATLANTIC AND SOUTHERN NIAGARAN

The Atlantic Niagaran has generally been recognized as belonging to a distinct province separated by a land barrier from the interior sea. This is made evident not only by the distinctness of the faunas, as exhibited in the Anticosti group and the development in Maine and New Brunswick, but also by the fact that the entire interior Appalachian region contains only shallow-water or continental deposits, indicating a continuous land mass in the East. That the Anticosti fauna nevertheless communicated with the interior is shown by its occurrence in Georgia and elsewhere in southeastern United States. This occurrence represents either a distinct embayment from the Atlantic, or the fauna migrated into the interior, going around the southern end of Appalachia, which may then have been separated from South America. An invasion of the interior from the south is indicated by the fauna of the Cape Girardeau or Alexandrian[1] formation of Illinois and Missouri, and perhaps also by the fauna of the

[1] See Savage, T. E., *Amer. Jour. Sci.*, Vol. XXV (1908), pp. 431–44; Schuchert, *Jour. Geol.*, Vol. XIV (1906), pp. 728, 729.

St. Clair[1] limestone of Arkansas. The Alexandrian series of Savage contains many types unknown from the true Niagaran, some Ordovicic genera also being present (Rafinesquina, Platystrophia, Rhynchotreta, Zygospira). Few typical Niagaran species occur, but the presence of the genera Favosites, Atrypa, Whitfieldella, Homoeospira, Schuchertella, Chlorinda, and Lichas (Metopolichas) indicates the Siluric age of this fauna. It probably represents an invasion from the south before the Niagaran transgression from the north had reached the southern Illinois region. Northward, in central and northern Illinois, this fauna seems to be wanting, the true Niagaran fauna here succeeding the Cincinnatian.

The Alexandrian is succeeded disconformably by 30 to 75 feet of limestones with a Lower Niagaran fauna. A transgression is indicated by the fact that "where the formation is thinnest, it is the lower, and not the upper layers that are absent."[2] The Niagaran fauna includes: *Favosites favosus*, *Halysites catenulatus*, *Atrypa rugosa*, *Orthis flabellites*, *O. cf. davidsoni*, *Plectambonites transversalis*, *Stricklandinia triplesiana*, and *Triplesia ortoni;* which grouping, as stated by Savage, corresponds to that of the Clinton of the Dayton, Ohio, region.

The invasion of the interior by a southern fauna, in later Niagaran time, seems to be indicated by the later Siluric formations of Tennessee and possibly in part by the Louisville limestone of Indiana and Kentucky. The higher beds of western Tennessee, called by Foerste[3] the Brownsport beds, and subdivided into the Beech River, Bob, and Lobelville formations by Pate and Bassler[4] contain faunas apparently not found in the typical or northern Niagaran formations, and which are well developed in the underlying series, named, in ascending order, Clinton, Oswego, Laurel, Waldron, Lego, and Dixon.

[1] Van Ingen, Gilbert, "The Siluric Fauna near Batesville, Ark., Part I," *Schoo of Mines Quarterly*, Vol. XXII (April, 1901), pp. 318–29.

[2] Savage, *op. cit.*, p. 435.

[3] Foerste, A. F., "Silurian and Devonian Limestones of Western Tennessee," *Jour. Geol.*, Vol. XI, pp. 554–715.

[4] Pate, W. F., and Bassler, R. S., "The Late Niagaran Strata of West Tennessee," *Proc. U. S. Nat. Mus.*, Vol. XXXIV, pp. 407–32. See also Roemer, *Die silurische Fauna des westlichen Tennessee*, in which the fauna of these higher beds is described.

E. THE MIDDLE SILURIC OR SALINAN

This is typically known only from New York, Michigan, western Ontario, northern Illinois, and Ohio, and is everywhere a series of more or less calcareous shales and gypsiferous beds, with salt beds up to 100 feet in thickness. The maximum development is in central New York and southern Michigan, where it exceeds 1,000 feet in thickness. In western New York it is only 350 feet thick. The only fossils known from the beds are from the lower (Pitsford) shales, where they represent the last survivors of the Guelph. They are chiefly Eurypterids (Hughmilleria, Eurypterus, etc.) and occur in muds alternating with dolomites carrying a Niagaran fauna. The Eurypterid fauna also occurs in the mud layers in the Shawangunk conglomerate, which hardly admits of any other interpretation than deposition by torrential rivers. This would make the Eurypterid fauna a fresh-water fauna, an interpretation which best corresponds with the distribution of these fossils geologically as well as geographically. The Salina series is best understood as a desert deposit. The absence of organic remains (with the exceptions noted), known to be abundant in all modern salt deposits of sea-margin origin; the thickness of the salt beds; their limitation to circumscribed basins,[1] the red color of the lower shales, their mud cracks, "Thongallen," etc., all point to a continental origin. The absence of true marine strata of Salina age[2] and erosion of the surrounding Niagaran beds further indicate that North America was above water. The salt was derived from the marine limestones of Niagaran and earlier age.

THE GREEN POND SHAWANGUNK CONGLOMERATES AND SUCCEEDING RED SHALES

The general retreat of the sea at the end of Niagaran time was marked in the east by an uplift followed by continental sedimentation. The series began with a conglomerate (Green Pond) 1,500 feet thick in northern New Jersey, but thinning northward to 500 feet at Ellenville (Shawangunk conglomerate), to 200 feet at Rosendale, and to nothing at Rondout. Southward and westward it thins

[1] See Walther, *Gesetz der Wüstenbildung*. Lack of space forbids the full discussion of this interesting problem. It will be treated at length in another paper.

[2] The so-called marine Salina of Maryland is of Monroan age.

to 700 feet at the Delaware water gap, to 400 feet at the Lehigh, and to less southward. The thinning is by failure of the lower beds, showing this to be a true non-marine overlap, and therefore stamping the series as of river origin. The Eurypterid layers in the upper beds are probably contemporaneous with the basal Eurypterid beds of the Salina of New York. The succeeding series of Longwood shales resembles the Juniata-Queenston, and, like it, has all the earmarks of a continental series formed under semiarid conditions. They thin from 2,385 feet in New Jersey to 120 feet at Cornwall, 75 feet at High Falls (High Falls shale); and 25 feet at Rosendale, and disappear farther north. Southward they thin likewise, while westward only the upper 400 feet of the series is shown in the red Lower Salina shales of Ithaca and Syracuse, New York, where they are succeeded by salt deposition and less than 200 feet at Buffalo. Like the conglomerate, the shales thin by failure of the lower beds, i. e., by non-marine overlap away from the source of supply.

F. THE UPPER SILURIC OR MONROAN

This is typically developed in southern Michigan, Ohio, and western Ontario, where it is divisible into Lower Monroe or Bass Islands series, 500 feet thick, or more; middle Monroan or Sylvania sandstone 30 to 150 feet thick; and Upper Monroan or Detroit River series, 300 to 400 feet thick.[1] The entire series is involved in gentle folding of early Devonic age, the Dundee resting upon the eroded surfaces of various members of the series.

The Lower Monroan represents an invasion from the Atlantic across Maryland, Pennsylvania, and southern Ohio, to Michigan and probably Wisconsin. Western Ontario was involved, but apparently not western New York. The fauna is Upper Siluric, genetically related to the Manlius limestone fauna, and, like it, representing an Atlantic type. The Upper Monroan fauna, on the other hand, is of a distinct type, especially in the lower members (Flat Rock, Amherstburg, and Anderdon beds). Besides being related to the later Niagaran fauna, it has a new coral and brachiopod element suggestive

[1] See Sherzer and Grabau, *Bull. Geol. Soc. Amer.*, Vol. XIX. The full discussion of these formations and their fauna will appear in the report of the Michigan Survey.

of Devonic affinities. This is further shown by the occurrence of Panenka and Hercynella in these beds. The highest division (Lucas) is characterized by gastropods, most nearly related to late Siluric types of northern Europe.

The Amherstburg beds of the Upper Monroan appear to be the chronologic equivalent of the Cobleskill of eastern New York, several characteristic species being common to both. It represents the junction of an eastern and a western sea, and a commingling of the fauna of both. The typical Upper Monroan coral and brachiopod fauna seems to have invaded Michigan from the northwest, a somewhat similar fauna appearing near the headwaters of the Saskatchewan. In Pennsylvania the Lewistown limestone appears to represent this horizon.

The Sylvania sandstone has all the characteristics of a wind-drifted sand. Its cross-bedding is of the aeolian type, its grains well rounded, pitted, grooved, and of uniform size; there is a total absence of impurities, and all the characteristics compare favorably with those of the sands of the Lybian desert of today. It indicates a period of land condition between the retreat of the Atlantic embayment (Lower Monroan) and the Pacific invasion of Upper Monroan time.

G. THE LOWER DEVONIC

The Lower Devonic comprises the Helderbergian and the Oriskanian of Clarke and Schuchert. The Helderbergian includes the Coeymans, New Scotland, Becraft, and Port Ewen. The latter is transitional to the Oriskany, and Chadwick proposes to unite it with that formation.[1] The Coeymans is the direct depositional successor of the Manlius, there being frequently a transitional zone between them, with a commingling of the fossils. The former extent of the Coeymans can be estimated from its occurrence at Syracuse and the uniform character which it maintains in that region. This indicates that the western shore of the Helderberg sea was west of Syracuse and perhaps in the region of Buffalo. The eastern and northern limit of the formation is indicated by its mergence into shore deposits in New Jersey, and the southward overlap of the later formations,

[1] *Science*, N. S,, Vol. XXVIII, p. 347.

the Virginia, western Tennessee, and Oklahoma occurrence of this series beginning with beds carrying a New Scotland fauna.[1]

The emergence of the North American continent at the end of Siluric time was accompanied by the first pronounced doming of the Cincinnati region and basining of the Michigan area. Local oscillations seem to have preceded this, but the first great movement apparently did not occur until the end of the Siluric. Between the Michigan basin and the Cincinnati dome were formed the Wabash anticline and the minor folds of Michigan, Ohio, and Canada. When these regions were again wholly submerged in Mid-Devonic time, the deposits of this later epoch came to rest on the beveled surfaces of various Siluric members (see Fig. 11). A subsequent movement

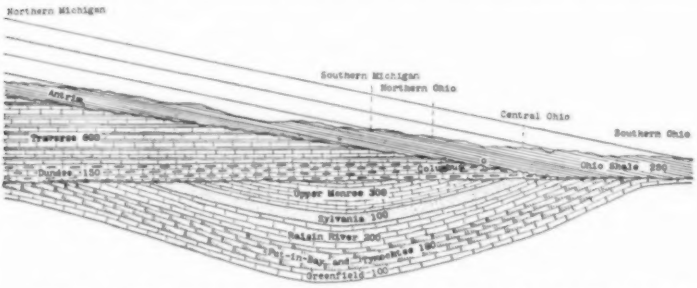


Fig. 11.—Section from northern Michigan to southern Ohio, showing the relationship of the Middle Devonic to the Siluric and of the Upper to the Middle Devonic. O = Olantangy shale.

in the same direction, at the end of Paleozoic time, threw the later beds into similar folds, while emphasizing those of the earlier series.

A marked hiatus occurs between the Helderbergian and Oriskanian. The former series is beveled, so that the Oriskany comes to rest, as it extends westward, upon lower and lower members of the Helderbergian, and finally upon the Manlius, and still farther west upon the Akron dolomite (Cobleskill). This beveling is in part due to retreatal "off-lap" but also to extensive erosion which indicates a time-period of some magnitude for the Oriskany. The depositional equivalent of this hiatus is found in the Gaspe region of Canada, where 550 feet of Oriskanian (Grand Greve limestone) follows

[1] See Grabau, *Bull. 92, New York State Museum.*

1,200 feet of Helderbergian (St. Albans and Bon Ami limestones), the succession being a conformable one.[1]

The Oriskany of the United States is mostly a sandstone, often of pure quartz grains, at other times calcareous. The source of the sandstone is to be sought in the sandstones of the eastern extension of the Siluric and Ordovicic formations, and perhaps in the exposures of the St. Peters and the Sylvania. It seems most likely that the distribution of the sand over eastern North America was largely effected by wind, during the long period of erosion preceding the submergence of the continent. On the westward extension of the Oriskany sea these accumulated sands were reworked and were transformed into the fossiliferous marine sands which they are found to be today. In the east, after a short period of sedimentation, an extensive accumulation of black muds occurred, forming the Esopus-Schoharie shale series. This has its greatest thickness at Port Jervis, whence it thins away in all directions, apparently by overlap. Since the source of the material was clearly in the east, and the overlap is toward the west, north, and south, the formation must be a subaerial fan. This is further indicated by the general absence of fossils, except for occasional intercalations, such as would be expected in a fan of this kind, probably rising but slightly above the level of the shallow Oriskany sea. The continuance of the Oriskany invasion is found in the spread of the limestone with the Schoharie fauna and the succeeding Onondaga submergence. During Onondaga and Hamilton time, continuous deposition and spreading of the seas went on, but at the close of the Middle Devonic, renewed emergence affected most of southern and southeastern United States, accompanied by erosion. This again was followed by the slow resubmergence, which commenced from the north and slowly advanced southward and eastward. The basal member of this transgressing series is the black shale, which, in northern Michigan, is of Lower Devonic (Genesee?) age, but becomes of later and later age southward, at the same time resting always on lower strata. Thus late Upper Devonic (Portage) black shale rests on Lower Hamilton in southern Michigan and northern Ohio; still later beds (Chemung) on the Onondaga (Columbus)

[1] See Clarke, J. M., "Early Devonic History of New York and Eastern North America," *New York State Museum Memoir 9*, 1908.

in central Ohio; while the highest beds rest on Monroan or even Niagaran, in southern Ohio. Continuing southeastward, the black shale rises in the series, until in eastern Tennessee it is of Lower Mississippic age, and rests on Lower Siluric or on Ordovicic strata.[1] (Fig. 11).

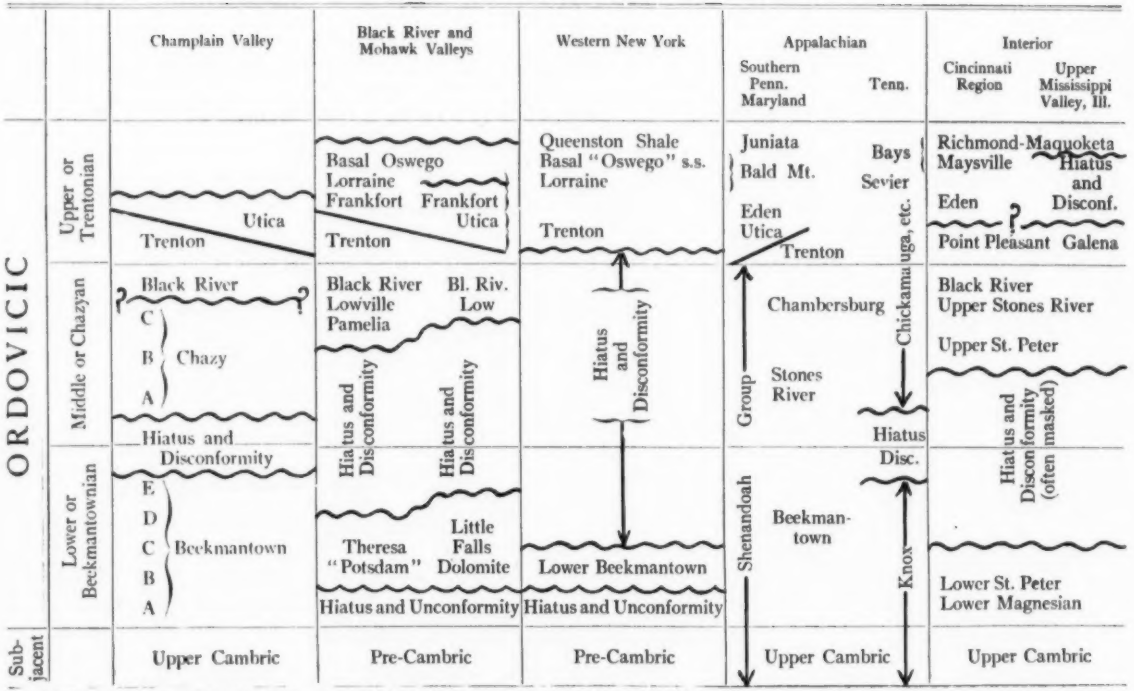
DISCUSSION

Professor Calvin

I have studied the Saint Peter sandstone in Iowa, Wisconsin, Minnesota, and Illinois, and nowhere have I seen any marked indications of cross-bedding such as would be consistent with an aeolian origin of the formation. In Iowa and Minnesota there are few structural bedding planes seen in fresh sections, but those that do exist are always horizontal and parallel. Bedding planes are more numerous in this sandstone west of Ottawa, Ill., but they are all precisely of the character one sees everywhere in aqueous sediments. When the Saint Peter is exposed on sloping hillsides, by a process akin to exfoliation, it breaks off in thick flakes parallel to the exposed surface and so often presents a false appearance of cross-bedding; but this feature has no relation to the original structure. One hardly needs to go to the Libyan desert to ascertain the characteristics of aeolian sands. The region around the south end of Lake Michigan affords ample opportunity, nearer home, to study the structural features and topographic forms of wind-blown deposits. I have seen nothing in the Saint Peter suggesting similar origin. Furthermore, the Saint Peter occasionally contains marine fossils, as shown by Winchell and Sardeson.

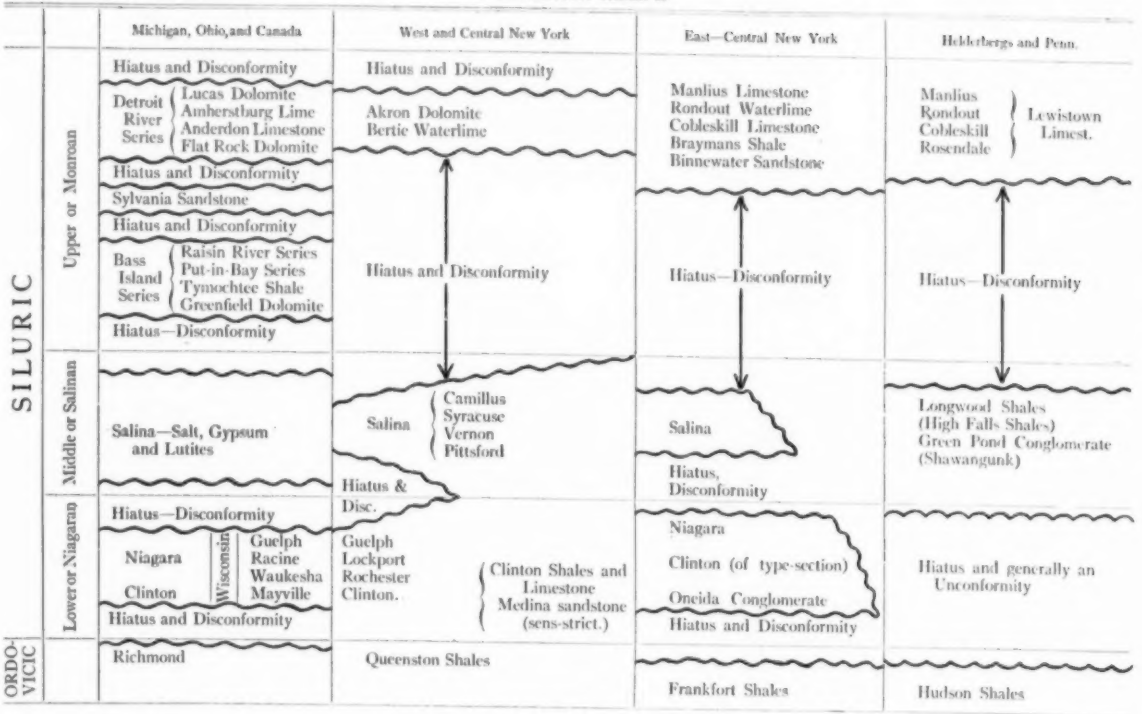
[1] See Grabau, "Types of Sedimentary Overlap," *Bull. Geol. Soc. Amer.*, Vol. XVII, pp. 593–613.

CORRELATION TABLE I



A "disconformity," as defined by Grabau, is an erosional unconformity, without discordance of dip.

CORRELATION TABLE II



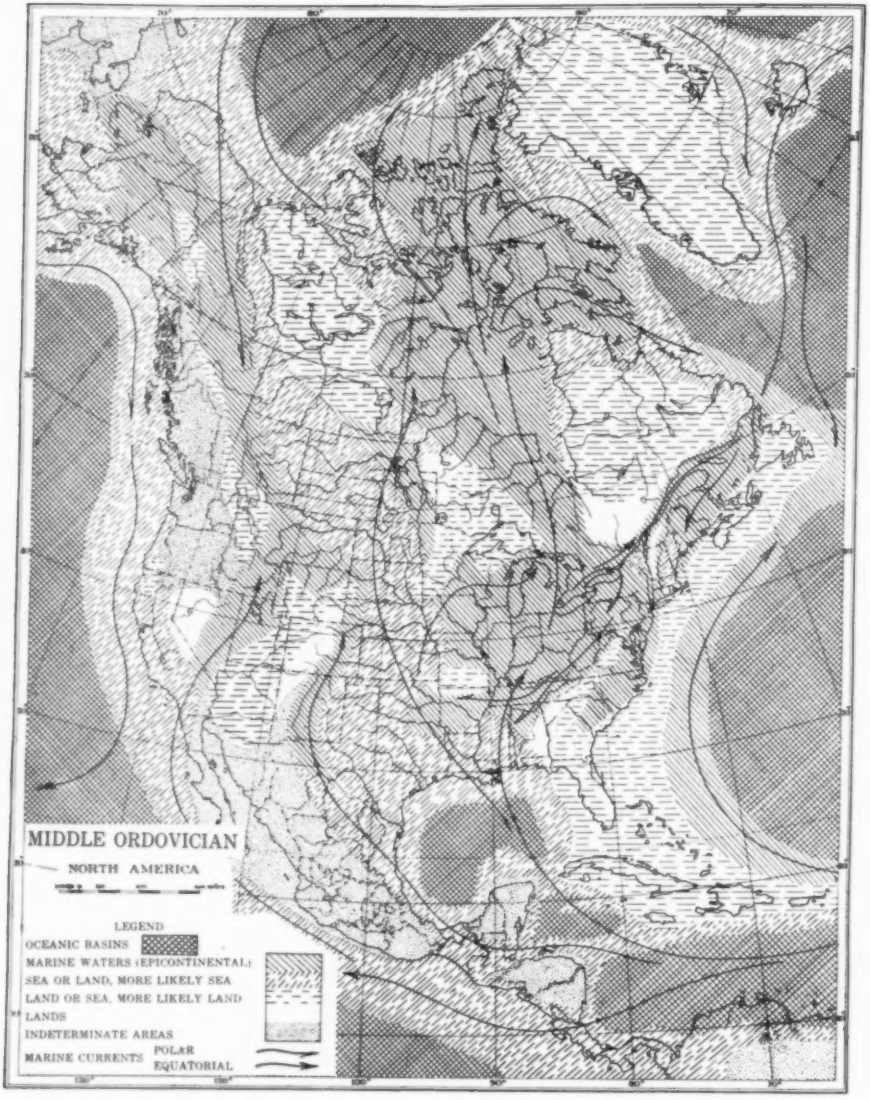
PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

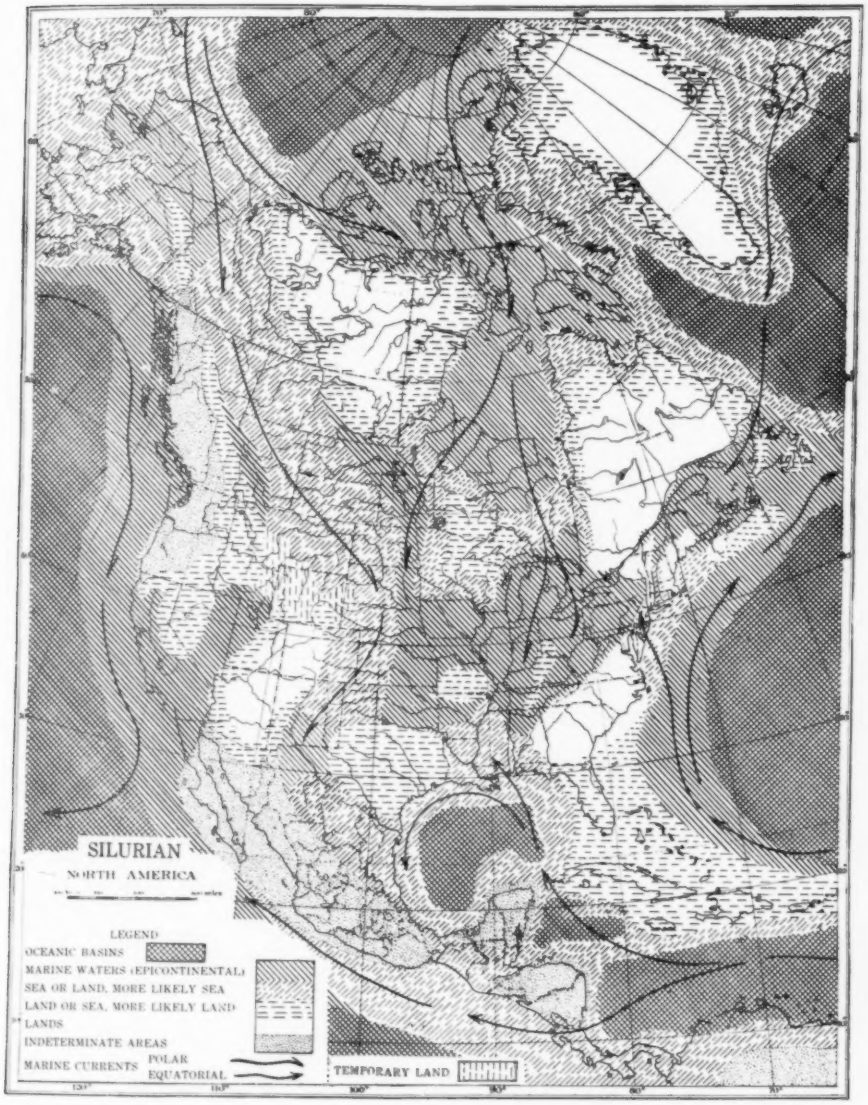
BAILEY WILLIS
U. S. Geological Survey

3. MIDDLE ORDOVICIAN NORTH AMERICA

The passage from the upper Cambrian to the Ordovician appears to be marked in many localities by inconspicuous but notable evidences of non-deposition or erosion which may be attributed to submarine scour or the actual subaërial denudation of low-lying lands. The phenomena differ from those which commonly accompany marked continental deformation. They are believed to have resulted from the deepening of ocean basins which gave rise to a widespread ebb of the epicontinental seas. Effects of continental warping of a subordinate character may naturally have accompanied the sub-oceanic movements. The conditions of oceanic circulation which result from a consideration of the probable distribution of seas and lands are those of general northward currents flowing from the Gulf of Mexico through to the Arctic. They carried with them the characteristic middle Ordovician fauna, which, however, developed local diversities in the eddies of the North American archipelago. In contrast to the central marine currents and their fauna we have the polar southward-trending return currents which may have been congenial to the graptolites. Their distribution would seem to explain the similarity of graptolite faunas in the eastern and western troughs. A peculiar circumstance is suggested in the occurrence of the graptolites in Arkansas. This is recognized on the map by the crossing of the arrows indicating marine currents. It is a well-established fact of oceanography that marine currents pass over or under one another, and this fact affords a possible explanation of the relations which appear to have existed in Tennessee and Arkansas. As a supplemental hypothesis the student should consider Professor Chamberlin's suggestion of an inversion of oceanic circulation which is based upon the possibility that saline equatorial waters may have been denser than, and have sunk beneath, relatively fresh and lighter

[1] Published by permission of the Director of the U. S. Geological Survey.


MIDDLE ORDOVICIAN
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS
POLAR
EQUATORIAL


SILURIAN
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
TEMPORARY LAND

polar waters. The conditions of circulation today are determined by temperature and not by salinity, but the differences of temperature which developed during the glacial period and which still persist are exceedingly great, and it may well be doubted whether temperature had a like effect in Ordovician time, when, as is established by the distribution of faunas, climatic conditions were relatively very equable.

4. SILURIAN NORTH AMERICA

The period covered by this composite map is essentially that of the Niagara. North America was still an archipelago. The continental plateau was widely submerged on the north and was still covered by an interior sea. On the east, however, lands appear to have been elevated in consequence of the Taconic orogenic movements which proceeded from the Atlantic basin, and shallow seas or lands appear to have extended across the region which is now that of the Gulf states. It has been suggested that the sea was generally absent from the western portion of the continent, but recent investigations in Alaska and Utah indicate the presence of a Silurian fauna and we are at least justified in an alternative assumption that marine conditions existed quite extensively, but presented a habitat unfavorable to the rich fauna that occupied the interior Niagaran sea. The conditions of marine circulation appear to have restricted the equatorial currents to the Atlantic on the east and to the Gulf on the south, while the polar currents coming along the coast of Siberia and along Greenland penetrated into the interior sea where the slowly circu lating waters became warm enough to afford a very genial habitat. As in the middle Ordovician, the climatic conditions were equable throughout wide ranges of latitude and marked differences of temperature probably did not exist.

CORRELATION OF THE MIDDLE AND UPPER DEVONIAN AND THE MISSISSIPPIAN FAUNAS OF NORTH AMERICA[1]

STUART WELLER

V

INTRODUCTION.
NORTH AMERICAN DEVONIAN PROVINCES.
The Eastern Border Province.
The Eastern Continental Province.
Middle Devonian of the Eastern Continental Province.
Upper Devonian of the Eastern Continental Province.
The Interior Continental Province.
Middle and Upper Devonian of the Interior Continental Province.
Junction of the Eastern Continental and Interior Continental Provinces.
The Western Continental Province.
NORTH AMERICAN MISSISSIPPIAN PROVINCES.
The Mississippi Valley Basin.
The Southern Kinderhook Fauna.
The Northern Kinderhook Fauna.
Early Mississippian Faunas of the Appalachian Basin.
Post-Kinderhook Faunas of the Mississippi Valley Basin.
Mississippian Faunas of the Appalachian Basin.
Mississippian Faunas of the Rocky Mountain Basin.
Mississippian Faunas of the Western Continental Province.

INTRODUCTION

In its essential features a problem in geologic correlation is an investigation in the parallel histories of two or more regions, basins, or provinces, involving the points of contact between these areas. Since it is the fossil faunas which most satisfactorily indicate these points of contact, correlation problems, as applied to the stratified rocks of an age younger than the pre-Cambrian, are largely questions in paleontologic interpretation.

All questions in correlation become progressively more complex as the territory occupied by the faunas under consideration is extended.

[1] Read before Section E of the American Association for the Advancement of Science, Baltimore, Md., December, 1908.

So long as one's observations are restricted to a limited area contained entirely within a single life province, the problems are usually simple, and some beds with similar lithologic characters and similar faunules usually may be traced from section to section without abrupt changes. However, when one's observations extend beyond the limits of a single province or subprovince, the factors in correlation multiply, and frequently the problem becomes one of extreme complexity. In solving these problems the history of the faunas under consideration must be diligently studied in order to determine the elements in their composition, the source of these elements, and their relations one to another, both biologically, geographically, and geologically. The solution also involves the investigation of the paleogeography of the region being studied.

One of the first considerations in connection with any correlation problem is the determination of the several faunal provinces involved and their geographic limits.

NORTH AMERICAN DEVONIAN PROVINCES

Upon the North American continent four well-defined faunal provinces may be recognized in the Devonian strata. These have been designated by Williams:[1] (1) Eastern Border Province, (2) Eastern Continental Province, (3) Interior Continental Province, and (4) Western Continental Province. Although the boundary between the Eastern Continental and Interior Continental provinces is now known to be somewhat different from that assigned by Williams, the names themselves express better than any others which have been proposed the geographic relations of the provinces, and will be used here.

The Eastern Border Province is confined to the easternmost extremity of the continent, within the maritime provinces of Canada and the State of Maine. The outcropping strata of the Eastern Continental Province extend from eastern New York westward across New York and Ontario into Michigan, southwestward along the Appalachians across New Jersey, Pennsylvania, Maryland, West Virginia, and Virginia, also down the Ohio Valley through Ohio, Indiana, and Kentucky to southern Illinois, and southward into Tennessee, northeastern Mississippi, Alabama, and Georgia. Outliers are found in

[1] *Am. Jour. Sci.* (3), XXXV, 51–59.

two regions which are at present wholly isolated from the main body of the province, (1) at Lake Memphremagog near the international boundary between Vermont and Quebec, and (2) southwest of James Bay in Canada. In both of these regions the faunas recognized are so like those of the Eastern Continental Province that there must have been direct communication to them during the life of the faunas.[1]

The Interior Continental Province is typically developed in Iowa, where the Devonian strata are exposed from Muscatine County on the Mississippi River, northwestwardly across the state into the southern border of Minnesota, and it includes also the Devonian strata of Rock Island and Calhoun counties, Illinois, and those of Central Missouri. Beyond this the Devonian beds of Manitoba and the Mackenzie Valley are to be included in this same province, which seems to be connected in a northwesterly direction with the Eurasian Devonian Province. The Western Continental Province is confined to the Great Basin region, and its faunas are best known from the studies of Walcott[2] upon the Devonian faunas of the Eureka District in Nevada.

Since the faunas of the Eastern Continental Province have a more complete and continuous history than those of either of the other provinces, and because they are much better known, their succession is taken as the standard with which the other Devonian faunas of the continent are compared.

THE EASTERN BORDER PROVINCE

For substantial additions to our knowledge of the Devonian faunas of the Eastern Border Province we are recently indebted to Clarke,[3] although contributions of great importance were made many years ago by the Canadian geologists, Logan and Billings. In this region the Helderbergian and Oriskany faunas of Lower Devonian age have a great development, and the faunas of the Gaspe basin give evidence that this region was a center of dispersion of these two faunas. During Middle Devonian time, in this same region, many of the Lower Devo-

[1] For composition of the Lake Memphremagog fauna see Ami, *Ann. Rep. Geol. Surv. Canada*, VII, N. S., 157J; also, Schuchert, *Am. Geol.*, XXXII, 155. For James Bay fauna see Parks, *Ont. Bureau Mines, Report for 1904*, Pt. I, pp. 180–91.

[2] *Monograph*, U. S. G. S., Vol. VIII.

[3] "Early Devonic History of New York and Eastern North America," *Mem. N. Y. State Mus. Nat. Hist.*, Vol. IX.

nian types of life persisted to such an extent that the Gaspe sandstone has sometimes been correlated with the Oriskany of the Eastern Continental Province. It has been shown by Clarke, however, that associated with these Lower Devonian types there is a much more important element which allies the fauna with the Hamilton of the interior, the evidence being sufficient fully to justify the correlation of the Gaspe sandstone with the Middle Devonian. The Onondaga fauna is not differentiated in the Gaspe region.

The origin of the Hamilton fauna in the Gaspe basin is assumed by Clarke to have been by migration from the interior by way of the Connecticut and St. Lawrence troughs, and the presence of a similar fauna, showing a mingling of Oriskany and Hamilton types, on the island of St. Helen's near Montreal, gives some strength to such an assumption. However, the possibility of a southern origin, by way of the Atlantic border, should not be lost sight of.

THE EASTERN CONTINENTAL PROVINCE

Middle Devonian of the Eastern Continental Province.—In the Eastern Continental Province two major divisions of the Middle Devonian, the Onondaga and the Hamilton, are clearly recognized. These two faunas, with only minor, subprovincial differences, are persistent throughout the province, in New York, Ontario, Michigan, the Ohio Valley both east and west of the Cincinnati arch, in southern Illinois, and even in northeastern Mississippi and northern Alabama. The Onondaga fauna is in part an evolution product from the subjacent Oriskany, but, in addition, there are included in it at least three conspicuous elements which are entirely new, the corals, the cephalopods, and the fishes. This fauna has a greater distribution to the north than the superjacent Hamilton, it alone being represented in the outlying areas at Lake Memphremagog and James Bay. East of the Cincinnati arch, which was evidently a peninsula at this time, the Onondaga fauna does not extend far beyond the Ohio River, but west of this arch it is clearly recognized as far south as northeastern Mississippi. Throughout this entire area the composition of the fauna is wonderfully uniform.

The origin of the new elements in the Onondaga fauna is not entirely clear. It has been suggested by the writer[1] that these elements

[1] *Jour. Geol.*, X, 429.

have immigrated from the north by way of the tract now occupied by the fauna about James Bay, but there are few facts to support this hypothesis in the known distribution of the Devonian faunas of the Arctic region except the presence of several genera of fishes which occur in the fauna in America and in Devonian strata in Spitzbergen. The mingling of the Onondaga and Oriskany faunas in western Ontario, however, suggests that this was the first point of contact between the immigrant fauna and the pre-existing Oriskany, and would therefore indicate a northern origin for the fauna as a possibility. Ulrich and Schuchert[1] have postulated a southwestern origin, and later Schuchert[2] has suggested a northeastern origin for the fauna through the St. Lawrence Gulf and the Connecticut trough, but there seems to be as little basis for either of these hypotheses as for its northern origin.

East of the Cincinnati arch the Hamilton epoch is initiated by the fauna of the Marcellus shale which is evidently of Atlantic origin in so far as it is not evolved from the Onondaga, but this eastern incursion was of brief duration and did not penetrate to the subprovince lying west of the Cincinnati arch. The Hamilton proper is introduced throughout the province, both east and west of the Cincinnati arch, by the appearance in the faunas of certain peculiar brachiopods which are apparently of southern hemisphere origin, the most conspicuous of which are *Tropidoleptus carinatus* and *Chonetes coronatus*. Aside from this southern element the Hamilton fauna is in large part a derivative from the subjacent Onondaga, a considerable number of species being common to the Hamilton and the Onondaga, while many Hamilton species are closely allied, apparently genetically, to forms in the Onondaga fauna.

In its geographic distribution the Hamilton fauna does not extend as far north as the Onondaga, but it has a greater distribution southward along the Appalachians. West of the Cincinnati arch it is clearly defined in southern Illinois; it is probably present with the Onondaga in northeastern Mississippi, although data are not at hand to make a definite statement to that effect, and it has been clearly recognized in northern Alabama.[3]

[1] *Rep. N. Y. State Pal.*, 1901, p. 652.

[2] *Am. Geol.*, XXXII, 156.

[3] Schuchert, *Am. Geol.*, XXXII, 152.

During the Hamilton period the sea retreated from the northern embayments in the James Bay region and the Connecticut trough, and at the same time it transgressed toward the south and occupied territory which had been dry land during Onondaga time, and connection was apparently established between the eastern and western subprovinces to the south of the Cincinnati arch, which at this time became an island.

Upper Devonian of the Eastern Continental Province.—During Upper Devonian time the faunas of the Eastern Continental Province were far more local in their development than they had been at any time during the Middle Devonian. At no time during the period was there so uniform a fauna as either the Onondaga or the Hamilton had been, distributed throughout the entire province. In the early Upper Devonian time the sea retreated northward from its greatest southward extension of Hamilton time, and later again transgressed toward the south and southwest until it extended much farther than it had in the earlier period, this retreat and readvance being recorded in the unconformity at the base of the Upper Devonian black shale which is commonly exhibited south of the Ohio River and to some extent north of that stream.[1]

The earliest Upper Devonian fauna in the province is the Cuboides fauna of the Tully limestone in New York, characterized by a totally new immigrant element in the Devonian faunas of the province, of which the brachiopod species *Hypothyris cuboides* is the most conspicuous representative. This fauna has been shown by Williams[2] to be closely allied to the Cuboides fauna of the European Devonian which initiates the Upper Devonian of that continent. The Cuboides fauna in America must have had a common origin with the same fauna in Europe, and the path of its immigration into the Eastern Continental Province of North America is commonly considered to have been by way of the Interior Continental Province.

Following the Tully limestone in the northeastern portion of the province is the Genesee black shale with a meager fauna of which the Lingulas are the most conspicuous members. In the southern portion

[1] Data concerning this unconformity have been assembled by Foerste, *Ky. Geol. Surv., Bull. No.* 7, p. 129.

[2] *Bull. G. S. A.*, I, 481–500.

of the province the entire Upper Devonian epoch is represented by a black shale which has been variously called the Ohio shale, the New Albany shale, or the Chattanooga shale, which is widely distributed in southern Ohio, Indiana, and Illinois, in Kentucky, Tennessee, and northern Mississippi, Alabama, and Georgia, and extends westward into northern Arkansas. Throughout the southern portion of the province this black shale rests unconformably upon the subjacent strata, and in some parts of Kentucky, at least, is unconformable upon Middle Devonian limestones. In the Ohio Valley the fauna in the basal portion of the black shale indicates its Genesee age,[1] but as the shale was a transgressing formation toward the south and southwest, its age in these directions becomes younger and younger, and at the extreme limits of its extension it may even be younger than any true Devonian, and be contemporaneous with the basal member of the Mississippian.

While these monotonous black shale conditions obtained in the south, a series of waves of faunal immigration were penetrating the northeastern portion of the province. In the Portage of western New York occurs the Intumescens fauna[2] characterized by its numerous goniatites of the type of *Manticoceras intumescens*. This fauna, like the Cuboides fauna of the Tully limestone, is of European origin. The path of its migration into New York is believed by Clarke to have been the same as that of the earlier fauna, by way of the Interior Continental Province, but Ulrich and Schuchert[3] express the opinion that it came in from the Atlantic basin by an eastern route. Following the Intumescens fauna, in the same general region, is a fauna in the High Point sandstone, at the extreme summit of the Portage group, characterized by *Pugnax* of the type of *P. pugnus*, which is another European immigrant, and which has many species in common with the Lime Creek shales of the Interior Continental Province in Iowa. Succeeding the High Point fauna is the typical Chemung fauna with *Spirifer disjunctus* and its associates, which again are European immigrants, but are associated with other forms which are of Hamilton derivation.

[1] For a summation of the opinions which have been held in regard to the age of the black shale, see Girty, *Am. Jour. Sci.* (3), VI, 385, 386.

[2] Clarke, "The Naples Fauna in Western New York," *Sixteenth Ann. Rep. New York State Geol.*, 1896, pp. 31–161; also *Mem. N. Y. State Mus.*, No. 6.

[3] *Loc. cit.*

In central New York the history is somewhat different in that the Intumescens fauna does not penetrate there in its typical expression, and the Ithaca beds, which are equivalent to the Portage, carry a fauna which is in large part a Hamilton derivative, this being followed by the Chemung fauna. Still farther east, in the same state, the Portage epoch is represented by the non-marine Oneonta sandstone which is followed by marine beds with a recurrent fauna, which pass upward into the Chemung. In the extreme eastern portion of New York the non-marine Catskill conditions were doubtless constant from the beginning of the Upper Devonian until its close.

THE INTERIOR CONTINENTAL PROVINCE

Middle and Upper Devonian of the Interior Continental Province.— In passing from the Eastern Continental to the Interior Continental provinces, both the stratigraphic and faunal conditions are found to be totally different in almost every detail. In New York, where the Middle and Upper Devonian beds of the Eastern Continental Province have their most typical development, a maximum thickness of more than 3,000 feet of strata is recognized, and in the Appalachians in Pennsylvania the thickness is much greater, but in Iowa the total thickness of the Devonian beds of the Interior Continental Province is less than 300 feet. The entire series of Devonian beds in Iowa are commonly referred to the Middle and Upper Devonian, the Upper beds being unconformable upon the Middle,[1] but the limits of these divisions do not correspond at all with the limits of the Middle and Upper divisions of the Devonian in the Eastern Continental Province.

In the Middle Devonian of the Iowa geologists two major divisions are recognized, the Wapsipinicon and the Cedar Valley. Both the Wapsipinicon and the Cedar Valley are made up of minor formational units of more or less local development, and of these the Independence shales occupy a position near the base of the Wapsipinicon. The fauna of the Independence shales is the oldest of the Devonian faunas of Iowa,[2] and it shows much in common with the fauna of the Lime Creek shale of the Upper Devonian of the same state.

In the Upper Devonian three formations are included in Iowa, the Lime Creek shales, the State Quarry beds, and the Sweetland Creek

[1] Calvin, *Jour. Geol.*, XIV, 575; also *Ia. Geol. Surv.*, XVII, 197.

[2] Calvin, *Bull. U. S. Geol. Surv. Terr.*, IV, 725.

shale. As regards the relations of these three formations Calvin says:[1] "The three units referred to the Upper Devonian—the Sweetland Creek shales, Lime Creek shales, and State Quarry limestone—do not lie one above the other, but each is locally developed and lies unconformably on the Cedar Valley limestones."

The lower beds of the Wapsipinicon stage, other than the Independence shale, do not furnish any considerable fauna, *Martinia subumbona* being the most conspicuous species, but the higher beds, as well as the succeeding Cedar Valley beds, are abundantly fossiliferous, and faunally the dividing-line between the Wapsipinicon and Cedar Valley stages presents no more conspicuous break than that between the successive beds included within the Cedar Valley.

In correlating these faunas of the Iowan Devonian with those of the Eastern Continental Province, difficulty is met with because of the few points of contact between the two faunas. The faunas in the two provinces are so distinctly different that we are forced to the conclusion that there could have been no free communication between the two regions, but that they must have been entirely separated during the whole or the greater part of Middle Devonian time by some barrier, probably a land mass. During Upper Devonian time there was much more in common between the Iowan and New York faunas, showing that communication had been established ere that time. In the correlation of the faunas in the two provinces the important point to determine is the time of the establishment of this communication. Williams[2] has shown that the Cuboides fauna of the Tully limestone in New York is a distinct immigrant fauna from the Eurasian province, probably by way of the Mackenzie Valley and Iowa. The characteristic species of this fauna is *Hypothyris cuboides*, a species which is represented in the Iowan faunas by *Rhynchonella intermedia* Barris, the Iowan form apparently being specifically identical with the New York species. In Iowa this species is limited in its range to the upper portion of the Wapsipinicon stage, where it is highly characteristic of one of the divisions of the Fayette breccia,[3] and where it is associated with *Gypidula comis*. Because of the limited range of this species in

[1] *Jour. Geol.*, XIV, 575; also *Ia. Geol. Surv.*, XVII, 197.

[2] *Bull. G. S. A.*, I, 481–500.

[3] Norton, *Iowa Geol. Rep.*, IV, 160.

these Iowan beds, it seems safe to conclude that these higher Wapsipinicon beds are essentially equivalent in time with the Tully limestone of New York. Furthermore, almost the only fossil species in the lower Wapsipinicon beds is *Martinia subumbona*, which also is a common Tully limestone species.

Another point of contact between the faunas of the Iowan and the New York provinces is found in the faunas of the Lime Creek shales of Iowa and the High Point sandstone near Naples, N. Y. The High Point bed lies at the extreme top of the Portage in the New York section, and in a total fauna of 26 species, 14 are also present in the Lime Creek beds of Iowa.[1] This large proportion of identical species may be considered as a sufficient basis for the essential correlation of the beds.

If these two correlations are correct, a basis is established for the correlation of the entire Devonian series of Iowa, the Wapsipinicon being, in the main, the time equivalent of the later Hamilton of the New York section, its termination being essentially contemporaneous with the Tully limestone, the Cedar Valley being contemporaneous with the Portage group of New York, and the Lime Creek being contemporaneous with the closing stages of the Portage and the opening of the Chemung. There is no evidence whatever of the presence of any beds of Onondaga age in Iowa.

The invertebrate faunas of the so-called Upper Devonian formations of Iowa are less prolific than those of the Cedar Valley beds. The Lime Creek fauna includes a number of forms which are recurrent from the Independence shales near the base of the Wapsipinicon, a distribution which suggests the unity of the entire Devonian fauna of Iowa, and, further, that the Lime Creek is not far removed from the subjacent beds although there is apparently an unconformity between them. The State Quarry beds contain a number of distinctly Devonian brachiopods, among which may be mentioned *Pugnax alta* which also occurs in the Lime Creek shales, but the most conspicuous feature consists of the fish remains, *Ptyctodus calceolus* being the most abundant form. In the Sweetland Creek shales invertebrates are few in number, a species of *Spathiocaris* being perhaps the most common, a species which also occurs in the New Albany black shale of southern

[1] Clarke, *Bull. U. S. G. S.*, No. 16, p. 75.

Illinois and Indiana, as well as in a basal Kinderhook shale in Missouri. At the base of the formation a thin band occurs which is frequently crowded with the teeth of *Ptyctodus calceolus*, the same species which is present in the State Quarry beds and one which also has a wide distribution at the very base of the Kinderhook formations.

Following the Devonian of the Interior Continental Province to the northwest, it is next well exposed in Manitoba, and has been well described by Tyrrell.[1] Approximately 510 feet of strata are recognized, the lower 100 feet not having afforded any fauna. The beds referred to the Middle Devonian (Winnipegosan) are characterized by the presence of *Gypidula comis* throughout, and by *Stringocephalus burtoni* in the upper portion. The last of these species does not occur in Iowa, but *Gypidula comis* is an abundant and characteristic member of the fauna of the upper beds of the Wapsipinicon stage, where it is associated with *Rhynchonella intermedia* Barris (*Hypothyris cuboides*). In western Europe *Stringocephalus burtoni* is the index fossil of the Stringocephalus limestone at the summit of the Middle Devonian, and occurs immediately beneath the Cuboides zone. The Devonian beds superjacent to the Stringocephalus beds in Manitoba have been referred to the Upper Devonian by the Canadian geologists, a correlation which is doubtless correct, since the faunal succession is similar to that in Europe, where *Stringocephalus burtoni* marks a distinct horizon at the summit of the Middle Devonian.

The Devonian fauna of the Mackenzie basin has been described by Whiteaves[2] and has been correlated with the Cuboides zone of Europe and New York, a correlation which seems to be based on substantial evidence. Seventy-six forms are specifically identified, twenty-nine of which are either present or are represented by close relatives in the European faunas of similar age, while twenty-two are identified with American Hamilton species, ten with Iowan and seven with Chemung forms. In the Mackenzie basin the Stringocephalus zone has not been so clearly recognized as in Manitoba, although it is indicated in at least one locality. The entire Devonian section in the Mackenzie Basin consists of 2,800 feet of strata, but a considerable part of the lower portion may be of greater age, and the entire fauna is

[1] *Geol. Surv. Canada, Ann. Rep.*, V, (N. S.), Pt. I, pp. 204–9 E.

[2] *Cont. Can. Pal.*, I, 197–253, pls. 27–32.

known from 200 feet of beds between 300 and 500 feet below the summit of the entire series.

JUNCTION OF THE EASTERN CONTINENTAL AND INTERIOR CONTINENTAL PROVINCES

As has been indicated in the previous discussion of the faunas of the Eastern Continental and Interior Continental Provinces, the time of the establishment of a path of communication between the two was at the very opening of the Upper Devonian, when the Cuboides fauna found its way into the East, but the relations of the Iowan faunas with those of the East is not such as to suggest an entirely unobstructed intermingling of faunas even after this communication was finally established. Schuchert has suggested in his paleogeographic maps[1] that this communication was by way of a narrow and somewhat tortuous strait, the "Traverse Strait," which passed from southeastern Iowa in a general northeasterly direction, across Illinois through the Lake Michigan basin to northern Michigan. Within the limits of this strait occur the Devonian beds near Milwaukee, Wis., and those of the Grand Traverse region of Michigan, where there is a greater commingling of eastern and western forms than elsewhere, as might be expected under the circumstances. The waters of this strait were separated from those of the Eastern Continental basin by the comparatively narrow Kankakee peninsula.

THE WESTERN CONTINENTAL PROVINCE

The Devonian strata of the Western Continental Province occur at various localities in the Great Basin region, and their faunas have been described by Walcott in his *Paleontology of the Eureka District*.[2] One hundred and eighty specifically identified forms are recorded, of which 61 are new and 119 are identified with already known forms. The composition of the previously known portion of the fauna is as follows: 83 species are identical with forms from the Eastern Continental Province, including New York, Michigan, and the Ohio Valley, the other 36 being known from Iowa and other parts of the Interior Continental Province. Of the eastern species 29 are found only in the Onondaga fauna, 21 only in the Hamilton, and 13 only in Devonian

[1] *Am. Geol.*, XXXII, Pl. 21; also, *Ia. Geol. Surv.*, XVIII, pl. 16.

[2] *Monograph*, U. S. G. S., Vol. VIII.

beds younger than the Hamilton; the remaining species are common to the Onondaga and the Hamilton, with one exception, which occurs in the Hamilton and the Chemung. From these figures it is evident that this Great Basin fauna contains a strong Onondaga element, 48 species in all. Of the Hamilton species neither *Tropidoleptus carinatus*,[1] *Chonetes coronatus*, nor any of the strictly foreign species in the fauna are recognized, the entire Hamilton element being of that association which seems to have originated from the Onondaga. Of the three highly characteristic elements of the Onondaga fauna of the East, corals, cephalopods, and fishes, we find 11 species of corals and 11 species of cephalopods, but none of the latter are identical with those of the East, although they are congeneric. Of icthyc remains but a single tooth was collected by Walcott, but in the Kanab Cañon of northern Arizona a strongly marked Devonian fish horizon is recorded,[2] although the composition of the fauna has not been made known.

In its entirety the Devonian fauna of the Western Continental Province may be said to be composed of a combination of two distinct elements: (1) the Middle Devonian fauna of the Eastern Continental Province, exclusive of the southern hemisphere element in the Hamilton, and (2) the fauna of the Interior Continental Province. These two elements are not fully differentiated in the faunas, since species from the Iowan or Mackenzie Basin faunas occur indiscriminately in either the lower, middle or upper divisions of the Great Basin Devonian. The Onondaga element also occurs through all of the divisions, although it is most conspicuous in the lower beds. Within this province there is no faunal evidence indicating the presence of Devonian rocks of greater age than the Onondaga, but sediments were doubtless deposited in the area contemporaneously with the Onondaga, Hamilton, and Upper Devonian of the Eastern Continental Province, but no beds can be correlated definitely with either of the eastern formations. The older of the beds are doubtless of greater age than the oldest Devonian beds of Iowa, although they may not be older than some of those of the Mackenzie Valley.

[1] *Tropidoleptus carinatus* has been recorded from the Pinon Range, Nevada, but the species has not been figured, and the identification has not been confirmed, *Monograph*, U. S. G. S., VIII, 276.

[2] Walcott, *Monograph*, U. S. G. S., VIII, 7; also *Am. Jour. Sci.* (3), XX, 225.

The path of communication between the Eastern Continental Province, in Onondaga time, and the Western Continental Province must have been indirect, although there was certainly some community of origin of the faunas in the two regions. If the northern origin of the Onondaga fauna, as has been suggested by the writer,[1] has sufficient foundation, which is perhaps doubtful, the fauna may have migrated southward into two epicontinental embayments, one into the Eastern Continental Province, by way of Hudson Bay and James Bay, and another farther west into the Western Continental Province. The mingling of the Onondaga and the Iowan faunas might be accounted for on this basis, since it is quite definitely recognized that the latter fauna has a northwestern origin, at least in so far as North America is concerned. One objection to this view is the fact that the Onondaga fauna is not represented among the known faunas from the Mackenzie Basin, although there is sufficient room for its occurrence in some of the older Devonian beds of that region which have not yet afforded any fauna. A southern pathway of communication between the two provinces is a possibility, although on such an hypothesis the absence of the southern hemisphere element of the later Middle Devonian faunas of the East is not easy to account for.

THE NORTH AMERICAN MISSISSIPPIAN PROVINCES

The early stages of the Mississippian period were marked by a continuation of the transgression of the sea in the south and southwestern part of the Eastern Continental Province, which had been initiated during Upper Devonian time, but it was extended also to the northwest. Before the close of the Kinderhook epoch, the sea had crossed the Kankakee peninsula and had surrounded the Ozark land which became an island or was perhaps entirely submerged, and had stretched away toward the Rocky Mountain land, so that the earlier Eastern Continental and Interior Continental provinces were merged into one great interior province with three subordinate basins or subprovinces, (1) the Appalachain Basin lying between Appalachia and the Cincinnati arch and extending from Michigan to Alabama, (2) the Mississippi Valley basin extending westward from the Cincinnati arch and merging with the Appalachian Basin to the south, (3)

[1] *Jour. Geol.*, X, 429.

the Rocky Mountain Basin. The Western Continental Province remained much as in Devonian time, faunally isolated to a great extent from the interior province. The Eastern Border Province was even more isolated, its faunal history, so far as known, having no points of contact with the interior.

The more complete and differentiated faunal history of the Mississippian is that of the Mississippi Valley Basin which will be used as a standard of comparison for the other provinces or subprovinces considered.

THE MISSISSIPPI VALLEY BASIN

The Southern Kinderhook fauna.—When the Upper Devonian or New Albany black shale is well developed in southern Indiana and Illinois, the initial Kinderhook bed, the Rockford limestone, follows it with no stratigraphic break. In following the Kinderhook beds to the north, however, they are found to succeed, unconformably, formations of much greater age. The same condition also probably holds in passing from Burlington, Ia., to the south, although the transition beds from the Devonian to the Kinderhook are not exposed in the Burlington section. An actual land barrier, the Kankakee axis of Schuchert, separated these northern and southern basins at the beginning of Kinderhook time, when each basin was occupied by its own distinctive and characteristic fauna. Before the close of the Kinderhook this barrier was submerged and a common fauna occupied the entire Mississippi Valley Basin.

The fauna of the Rockford limestone contains new elements which were unknown in the preceding Devonian faunas, associated with certain other forms which are clearly Devonian derivatives. The typical expression of this more southern type of the Kinderhook fauna, however, is found in the Chouteau limestone of central and southern Missouri and Illinois, although there are several modifications of the fauna in the various more or less local formational units of the Kinderhook of this region. Among other things the fauna contains numerous goniatites, some of which are notable forms and have no relationships with any of our known Devonian goniatites. *Aganides rotatorius*, from the Rockford goniatite bed of Indiana, is identical with a form in the basal Mississippian beds of Belgium and Ireland. Associated

with this form at Rockford is *Prodromites gorbyi* which occurs also in the Chouteau limestone of central Missouri. This latter goniatite is the most advanced one of the Mississippian faunas, having, as it does, a secondarily lobed suture such as, at no very distant period in the past, was considered to be characteristically Mesozoic in type. Another peculiar cephalopod in the fauna is *Tribloceras digonum* which occurs in the fauna at various localities. A peculiar type of pelecypod is found in the genus *Promacrus*, which occurs also in the early Mississippian beds of Belgium. These and many other forms in the fauna characterize it as something distinctly younger than any Devonian fauna, with numerous bonds of affinity uniting it with the higher and more typical Mississippian faunas. However, there occur associated with these characteristic portions of the fauna certain species, especially among the pelecypods, which are clearly Devonian derivatives, and, strange to say, their relationships are usually with members of the Hamilton fauna, rather than with the higher Devonian faunas of the Eastern Continental Province. The Hamilton relationships of the fauna are perhaps best seen in the fauna of the Glen Park limestone,[1] where the pelecypods and gastropods are all close allies of Hamilton forms, and where one form even seems to be specifically identical, but associated with these is a member of the highly characteristic Mississipian genus *Syringothyris*.[2]

The origin of this southern Kinderhook or Chouteau fauna is believed to have been in the Atlantic Basin, where Middle Devonian faunas of Hamilton type had probably retreated as the Upper Devonian immigrants became established in the Eastern Continental Province, or where they had persisted during Upper Devonian time, having never been encroached upon by the immigrants. During the long lapse of time most of the species had been modified, and there had been absorbed into the fauna a new element from some unknown region. The return of this fauna into the Mississippi Valley Basin marks the opening of the Kinderhook epoch and the Mississippian period.

[1] Weller, *Trans. St. Louis Acad. Sci.*, XVI, 435–71.

[2] The species described in the *Fauna of the Glen Park Limestone* (*loc. cit*). as *Spirifer jeffersonensis*, has since been definitely identified as a member of the genus *Syringothyris*.

The Northern Kinderhook fauna.—North and west of the Kankakee peninsula, in the eastern portion of the Devonian Interior Continental Province, the earliest Mississippian faunas were as distinctly different from those of the southern portion of the Eastern Continental Province, as had been the preceding Devonian faunas. The oldest of these northern Kinderhook faunas is that of the Chonopectus sandstone[1] at Burlington, Ia., and elsewhere in Iowa and Illinois. This fauna contains a large Devonian derivative element, especially among the pelecypods, but its relationships are with the Chemung faunas of the Upper Devonian, and are totally different from the Devonian derivatives of the southern fauna. Another modification of the northern Kinderhook fauna is found in the Louisiana limestone, which is believed to be in part contemporaneous with, and in part younger than, the Chonopectus fauna. One of the most characteristic members of this northern Kinderhook fauna is the striated rhynchonelloid genus *Paraphorhynchus* which occurs also in the early Mississippian faunas of northwestern Pennsylvania.

In the Burlington, Ia., section the Chonopectus fauna occurs at the summit of a series of shales, becoming arenaceous above where the fauna occurs, which have a total depth of 160 feet. The lower 100 feet of the formation lies beneath the level of the Mississippi River, so that the contact with the underlying formation and the age of the subjacent bed is not known. This lower bed, however, is probably Devonian, and is not unlikely the Cedar Valley limestone, since that formation lies unconformably beneath the Kinderhook beds farther south in Calhoun County, Ill. If this is the case then these lower shales of the Kinderhook correspond in position with the Sweetland Creek shales of the Upper Devonian in Muscatine County, Ia. There is, however, perhaps insufficient faunal evidence upon which to base a definite correlation of these two shale formations. The most conspicuous faunal character of the Sweetland Creek beds is the presence of numerous *Ptyctodus* teeth in the basal bed, occupying a few inches above the unconformity. A similar *Ptyctodus* bed occurs not infrequently at the base of the Kinderhook in both the northern and southern provinces. Such is the case at the base of the Louisiana limestone at Louisiana, Mo., where *Ptyctodus* occurs abundantly in a thin shale

[1] Weller, *Trans. St. Louis Acad. Sci.*, X, 57–129; also *Jour. Geol.*, XIII, 617–34.

bed beneath the limestone. In southeastern Missouri a one-foot bed of sandstone occurs at the base of the Kinderhook with numerous phosphatic nodules and some worn *Ptyctodus* teeth. In southwestern Missouri a thin formation at the base of the Kinderhook has been described by Shepard[1] as the Phelps sandstone, in which *Ptyctodus* teeth are abundant, and the same conditions obtain at Providence,[2] in central Missouri. In all of these localities the same species, *Ptyctodus calceolus* N. and W., seems to be the usual form. Occupying, as these *Ptyctodus* beds do, a position immediately superjacent to a more or less profound unconformity, it is not likely that it is strictly contemporaneous in all of these localities, but that they are all associated with one general geologic movement, and are contemporaneous within comparatively narrow limits, is quite certain. The presence of the remains of this fish fauna, in both the southern and northern Kinderhook provinces, while the invertebrate faunas are so distinct, is doubtless due to the fact of the greater mobility of the fishes, and their greater powers of adaptation to certain changing conditions. Besides these fish remains, the most common fossil in the Sweetland Creek beds is a crustacean belonging to the genus *Spathiocaris*, which also occurs in the Upper Devonian black shale in southern Indiana and Illinois, and in a basal Kinderhook shale in southwestern Missouri. This crustacean, like some of the Lingulas, seems to be associated rather with a peculiar type of sediment than with a definite time period of narrow limits. Neither the *Ptyctodus* nor the *Spathiocaris* have been found in the basal Kinderhook shales at Burlington, but the fauna of the basal portion of the formation is of course not known.

During the progress of Kinderhook time the sea was encroaching from both the north and the south, until before the close of the epoch free communication was established between the earlier separated provinces and the fauna of the southern province became the dominant type throughout the entire Mississippi Valley Basin. This northern incursion of the southern fauna is well exhibited in the uppermost 15 feet of the Kinderhook section at Burlington and elsewhere.

From the outline of the faunal history here given, it is evident that the arrangement of the Kinderhook formations into three successive

[1] *Mo. Geol. Surv.*, XII, 77.

[2] "Bed No. 4, Stewart," *Kansas Univ. Quart.*, IV, 161.

divisions, the Louisiana, Hannibal, and Chouteau, as has usually been done, does not express the proper relationships of the faunas. The Chouteau fauna, in some of its expressions, is without doubt as old as the Louisiana fauna, and it is as impracticable to make one continuous section to contain all of the Kinderhook formations, as it would be to make a standard Devonian section to include the formations of New York and Iowa.

Early Mississippian faunas of the Appalachian Basin.—In the waters between the Cincinnati arch and the old Appalachian land in early Mississippian time, the faunal conditions were more like those of the southern Kinderhook province than the northern. In the Bedford shale of that basin a fauna occurs which is largely of Devonian derived species, and like the southern Kinderhook faunas these species have their relationships with Hamilton rather than with Upper Devonian forms. The succeeding formations in Ohio constitute the several members of the Waverly group with faunas showing more or less close relations with those of the southern Kinderhook. In the northern part of the basin, as in the Waverly beds of northwestern Pennsylvania, the presence of such forms as *Paraphorhynchus*[1] suggest relationships with the northern Kinderhook faunas of the Mississippi Valley, a relationship which might have been established by faunal migration from the West to the East by way of the Traverse Strait and Michigan.

Post-Kinderhook faunas of the Mississippi Valley Basin.—With the submergence of the Kankakee Peninsula and the partial or complete submergence of the Ozark land, the source of the clastic sediments in the immediate Mississippi Valley region was removed, and a great period of limestone formation was initiated which is best exemplified in the Burlington and Keokuk formations. The fauna of this clear sea was in large part an outgrowth of the later Kinderhook faunas, and is best characterized by the wonderfully rich crinoidal element.

The fauna of the formations which together constitute the Osage division of the Mississippian is in some respects unique. The great crinoidal element is in large part or wholly indigenous to this province,

[1] *Rhynchonella medialis* and *R. striata* Simpson (*Trans. Am. Phil. Soc.*, XV, 144), from Warren County, Pa., are members of this genus.

although it had its beginnings in the preceding Kinderhook. No locality in the world, so far as known, has furnished so large a number of crinoids of similar age, either in genera, species, or individuals, as this Mississippian province. The fauna, in its entirety, exhibits much in common with the mountain limestone of England, Ireland, and elsewhere in Europe. Many species of brachiopods in the formations either are identical or are so closely allied as to be difficult of separation, and the correlation of the Osage with the Mountain Limestone of England, or at least of some part of it, is based upon substantial evidence. Evidence sustaining the indigenous character of the crinoidal element in the fauna is found in a comparison of these forms from the Osage of the Mississippi Basin and from the Mountain Limestone of Europe. Every genus in the Mountain Limestone occurs also in the American faunas, while there are many genera which do not occur outside of the Mississippi Basin; furthermore, all of those genera which occur in both this Mississippian province and in Europe are represented by a larger number of species in America. These facts seem to indicate that the Mississippi Valley Basin was the metropolis for this great crinoidal fauna.

During this period the Cincinnati arch was above sea level, and from this island clastic sediments were being deposited off its western and southwestern shore, which constitute, in part at least, the Knobstone formations of Indiana and Kentucky, although the basal portion of the Knobstone is undoubtedly of Kinderhook age. The faunas associated with these clastic sediments are usually more meager than in the calcareous sediments of the clear seas farther west, and are somewhat different in character; however, they possess much in common as is evidenced by the wonderfully prolific crinoid fauna of the Crawfordsville beds in Indiana.

The later phases of the Osage sedimentation became more clastic, especially toward the north, doubtless because of the elevation of the land to the north, and in the Keokuk formation numerous shaly layers occur, intercalated between limestone beds. The shales become more and more dominant until, in the Warsaw formation, shales constitute the major portion of the sedimentation. In the southern portion of the Mississippian Basin this change in sedimentation was less or even not at all effective, since the Warsaw, as a distinct shale

horizon, is scarcely or not at all recognizable beyond a short distance south of St. Louis. The fauna of these shaly Warsaw beds is more or less closely allied to that of the subjacent formations, but it contains numerous species which are quite distinct and some which are either identical with, or related to, members of the superjacent faunas.

Subsequent to the Warsaw sedimentation the land to the north of the Mississippi Valley Basin was elevated. The Salem limestone which lies immediately above the Warsaw has a thickness of only 8 or 10 feet at Warsaw, Ill.,[1] where the formation consists of an impure, arenaceous limestone. To the south it increases in thickness to a maximum of about 100 feet, and is for the most part a very pure limestone, although magnesian layers are not unusual. The formation extends eastward beneath the younger formations, and is again exposed in western Indiana, off the western shore of the old Cincinnati island. A notable feature of the formation is the presence in it, throughout its entire geographical extent, of more or less extensive oölitic beds.

The fauna of the Salem limestone, commonly known as the Spergen Hill fauna, contains many diminutive forms, one of the most common species being *Cliothyris hirsuta*, which was present in a Kinderhook oölite at Burlington, Ia. Several small forms of *Conocardium* are also common in the fauna, one of the species, *C. meekana*, being somewhat closely allied to *C. pulchellum* from the same Kinderhook oölite. A comparison of the fauna with the Mississippian faunas of other parts of North America indicates a close relationship with certain faunas far to the northwest in Montana and Idaho. Meek[2] has recorded a fauna from a limestone in Idaho in which nearly one-half of the forms are identical with Spergen Hill species, and in the Yakinikak limestone[3] in northwestern Montana a similar fauna also occurs. These limestones in Montana and Idaho are doubtless to be associated with the Madison limestone of the Yellowstone National Park, in which occurs a fauna having relationships with the Kinderhook of the Mississippi Valley, and especially with that of the Kinderhook oölite bed at Burlington, Ia., a relationship which may account for the partial recurrence in

[1] *Ill. State Geol. Surv., Bull. No.* 8, p. 90.

[2] *Am. Jour. Sci.* (3), V, 383.

[3] *Bull. Geol. Soc. Am.*, XIII, 324.

the Salem limestone of a fauna which has some features in common with this earlier fauna of a similar earlier oölitic bed.

Superjacent to the Salem is the St. Louis limestone which attains a maximum thickness of 250 feet, but in the northern portion of the Mississippian province it is reduced in thickness and lies unconformably upon the Salem, this unconformity being well shown near Warsaw, Ill. This unconformity indicates that the Mississippian sea retreated to the south during late Salem time, and readvanced in early St. Louis time. The retreat did not reach as far as Alton, Ill., however, as near that city the succession is perfectly conformable. The lowermost bed of the St. Louis in the north is a conspicuous limestone breccia which may be a northward continuation of a brecciated horizon near the middle of the formation in the region about St. Louis and Alton, but in following the formation to the south this brecciated horizon becomes less conspicuous and disappears. The fauna of the St. Louis is on the whole a meager one, and is quite different from that of the Salem. In some respects it suggests a recurrence of the Osage fauna, although the species are essentially all different, and some forms, of which the coral *Lithostrotion canadense* is perhaps the most notable, are distinctly new elements in the fauna.

The St. Louis is followed conformably by the Ste. Genevieve limestone. This formation differs from the St. Louis and resembles the Salem in the presence of oölitic beds, and with the recurrence of these conditions favorable for the formation of oölitic limestone, there is also a recurrence of the Salem fauna. Many species of the Ste. Genevieve are identical with those in the Salem, although the fauna contains species also which are characteristic to it. Among the latter a conspicuous one near Alton and in Monroe County, Ill., is *Pugnax ottumwa*, this species being present to the exclusion of all others in some localities. The abundance of the same species in the Pella beds of Iowa, the highest division of the so-called St. Louis of that state, suggests the correlation of these beds with the Ste. Genevieve rather than with any part of the St. Louis proper. This occurrence in Iowa is in accord with conditions elsewhere which indicate that the Ste. Genevieve was a time of great expansion of the Mississippian sea in all directions. It was at this time only, during the entire Mississippian period, that limestone conditions obtained in the northern part of the

more or less inclosed Appalachian Basin east of the Cincinnati island, where the Maxville limestone represents the Ste. Genevieve formation of the Mississippi Valley. To the southwest, in northern Arkansas, the Spring Creek limestone, a formation which, with the Batesville sandstone, is essentially contemporaneous with the Ste. Genevieve, and probably uncomformable upon the subjacent Osage beds, carries a most remarkable fauna with peculiar immigrant forms from the far southwest,[1] a faunal character which indicates that the Mississippian sea reached so far in that direction as to communicate with the Western Continental Province, where these peculiar forms had existed, some of them having persisted from Devonian time.

Subsequent to the great extension of the sea during Ste. Genevieve time the northern portion of the Mississippi Valley Basin became dry land, and so remained until it was reoccupied by the sea in Pennsylvanian time, with only a partial readvance in early Chester time. In the extreme southern portion of Illinois and in Kentucky, Ulrich[2] has recognized three members in the Ste. Genevieve formation, the Fredonia, the Rosiclare, and the Ohara, but in all the region north of Chester, Ill., the upper portion is wanting and the superjacent Cypress sandstone rests unconformably upon the lower beds of the Ste. Genevieve. The higher beds of the Ste. Genevieve in the extreme southern Illinois, especially the Ohara beds of Ulrich, bear a fauna which has much in common with the faunas of the Chester above the Cypress sandstone, but even here there is possibly an unconformity between these beds and the Cypress.

The Cypress sandstone initiates the Chester, the closing epoch of the Mississippian in the typical portion of the Mississippi Valley Basin, during which period the conditions of sedimentation were continually shifting, there being interbedded limestone, shale, and sandstone formations, the limestone and shale predominating below, above the initial Cypress sandstone, and the sandstones being more conspicuous above. No remnant of these beds is preserved, so far as known, north of a point some miles south of St. Louis, although it is possible that the Chester sea extended further north than this. It is quite certain, however, that this sea never had the great extent to the

[1] Williams, *Am. Jour. Sci.* (3), XLIX, 94–101.

[2] *Professional Paper*, U. S. G. S., No. 36, p. 38.

north which had obtained during some of the earlier Mississippian periods.

The faunas of the Chester beds have a certain individuality of their own, although the successive limestone beds, in which the fossils mostly occur, have not yet been faunally differentiated with any great success. A conspicuous feature of the fauna is the presence of numerous blastoids of the genus *Pentremites*, and bryozoans, especially of the genus *Archimedes*. Among the brachiopods, especially, there is some recurrence of species identical with, or closely allied to, forms in the Salem and Ste. Genevieve limestones, but this characteristic is not limited alone to the brachiopods.

In the typical portion of the Mississippi Valley Basin the Mississippian period closes with the withdrawal of the Chester sea. Farther to the southwest, in Arkansas, however, toward the more open sea, it has been suggested by Ulrich[1] that similar faunas persisted into beds which are really of Pennsylvanian age, under which interpretation the line between the Mississippian and the Pennsylvanian, in that region, would be somewhat arbitrarily drawn. It is not improbable that the Arkansas beds are younger than any in the Mississippi Valley, yet that fact should not necessarily be considered as sufficient basis for referring them to the Pennsylvanian. The time boundary between the two periods should be marked by the time of maximum withdrawal of the sea or the subsequent readvance during which new sets of conditions were introduced.

MISSISSIPPIAN FAUNAS OF THE APPALACHIAN BASIN[2]

During Mississippian time the Cincinnati arch constituted a barrier between the central Mississippian sea and the Appalachian basin, a gulf which lay between this island and Appalachia. Into this basin clastic sediments were being carried from the east, north, and west, so that the pure limestones of the Mississippi Valley are absent, and the faunas are neither so prolific nor so well differentiated. In this basin the Mississippian formations are included within the Pocono and Mauch Chunk formations of Leslie. The most definite point of faunal contact between this basin and the Mississippi Valley Basin is found in

[1] *Professional Paper*, U. S. G. S., No. 24, p. 109.

[2] For a detailed description of the stratigraphy and correlation of the Mississippian of the Appalachian Basin, see Stevenson, *Bull. Geol. Soc. Am.* XIV, 15–96.

the Maxville limestone, whose fauna is to be correlated essentially with the Ste. Genevieve of southern Illinois and Missouri. It has been shown by Stevenson[1] that only the upper portion of the Pocono is of Mississippian age, and that this part is stratigraphicaly continuous with the Waverly group of Ohio. The basal member of the Waverly group, in the more general application of that term, is the Bedford shale in which occurs a fauna with Hamilton affinities.[2] As has already been pointed out, this fauna is believed to be associated with the incursion of the Hamilton-like forms which constitute one element in the southern Kinderhook faunas. The composition of the succeeding Waverly faunas has been more carefully studied by Herrick[3] than by anyone else, and they exhibit throughout more or less affinity with the Kinderhook faunas of the Mississippi Valley Basin. Numerous members of the fauna suggest a Devonian derivation sometimes from Hamilton and sometimes from Chemung progenitors, as if they were to some extent a mingling of the two Kinderhook faunas of the Mississippi Valley. These Waverly faunas are, however, in no wise to be considered as contemporaneous with the Kinderhook alone of the Mississippi Valley, but they must also represent the Osage. In the Appalachian Basin, with its continuity of clastic sedimentation, environmental conditions similar to those of the Kinderhook persisted through Osage time, consequently there is no sharp differentiation of the faunas as there was in the Mississippi Valley where the period of clastic sedimentation was displaced by the clear seas in which nothing but calcareous sediments were deposited. For this reason the typical Burlington and Keokuk faunas do not occur in the Appalachian Basin, but an occasional member of these faunas found its way into the basin and such forms left records which are of value in the correlation of the faunas.

Outside of Ohio little or no detailed faunal study of these beds has been made, but Stevenson[4] has pointed out the stratigraphic correlation of the beds throughout the Appalachian Basin from Pennsylvania to Alabama.

[1] *Loc. cit.*

[2] Herrick, *Geol. Surv. Ohio*, VII, 507.

[3] A summary of Herrick's work is to be found in *Geol Surv. Ohio*, VII, 495–515.

[4] *Loc. cit.*

In the Mauch Chunk series of earlier authors, Stevenson[1] recognizes three members, a lower the Tuscumbia, a middle the Maxville, and an upper the Shenango. Toward the close of Pocono time there was a marked contraction of the sea in the Appalachian Basin, just as was the case at a corresponding time in the Mississippi Valley Basin. This contraction was of such proportions that the Tuscumbia beds were not deposited in Ohio in the area occupied by the earlier Waverly, except at the Kentucky border, but, as in the west, there was a readvance of the sea until it had reached its maximum extent in the deposition of the Maxville limestone which is to be correlated essentially with the Ste. Genevieve limestone of the Mississippi Valley. Such a correlation would make the Tuscumbia essentially contemporaneous with the St. Louis limestone of the Mississippi Valley, a correlation which is sustained by the paleontologic evidence. The Shenango is said to contain fossils characteristic of the Chester of the Mississippi Valley,[2] and may be correlated with that formation.

MISSISSIPPIAN FAUNAS OF THE ROCKY MOUNTAIN BASIN

In Montana and elsewhere in the northern Rocky Mountain region, limestones of Mississippian age are widely distributed, although but little data in regard to the faunas have been published. The most notable contribution to our knowledge of these faunas is that of Girty on the Carboniferous fossils of the Yellowstone National Park.[3] The faunas here described are distributed through more than 1,600 feet of strata of the Madison limestone, but they do not show any such differentiation as is recognized in the Mississippi Valley. One general fauna persists with but minor changes throughout the entire series and this fauna shows many affinities with the southern Kinderhook faunas of the Mississippi Valley, as well as with the fauna of the Salem limestone. Faunas allied to that of the Salem have also been detected elsewhere in the region, as the Idaho fauna noted by Meek and the fauna of the Yakinikak limestone already mentioned. These relations suggest that in this northwestern region a long-lived fauna, having more or less close relationships with the Salem fauna, was contemporaneous with the larger part of the entire Mississippian series of the

[1] *Op. cit.*, p. 85.

[2] Stevenson, *op. cit.*, p. 85.

[3] *Monograph*, U. S. G. S., XXXII, Pt. 2, pp. 479–599.

Mississippi Valley. At intervals this fauna made incursions into the Mississippi Valley Basin, as is evidenced by its representatives in the Kinderhook oölite at Burlington, Ia., in the Salem limestone, again in the Ste. Genevieve, and to some extent also in the Chester. That this is not a complete interpretation, however, is shown in the occurrence of a group of crinoids described by Miller and Gurley from near Bozeman, Mont.,[1] which strongly suggests the crinoid fauna of the lower Osage horizons of the Mississippi Valley. It is not improbable that when our knowledge of these faunas in the northwest is expanded, we may be able to recognize elements related to most or all of the faunal divisions of the Mississippi Valley. The evidence at present available suggests that this region occupied a distant part of the same sea which was present farther to the southeast, and that there was more or less unobstructed means of faunal communication between the two regions.

From the Lake Valley region in New Mexico, there has been described an early Mississippian fauna[2] which is a close ally of the fauna of the Fern Glen formation at the summit of the Kinderhook in the Mississippi River section south of St. Louis. This occurrence idicates that the Mississippian sea had transgressed at least as far to the southwest as New Mexico by the close of Kinderhook time, and that means for faunal communication was unobstructed in that direction.

The Mississippian faunas from Colorado have been described by Girty[3] who has reported on materials collected in nine separate regions from the Ouray, Leadville, and Millsap limestones. All of these faunas are separated into two groups by that author, both of which are considered to be of essentially the same age, early Mississippian, probably Kinderhook or early Osage. The composition of the fauna is strikingly like that of the Madison limestone of the Yellowstone National Park, its relationships being especially with the Chouteau of the Mississippi Valley Basin, but the presence of such forms as *Eumetria marcyi?*, *Straparollus cf. spergenensis*, *Fenestella serratula?*,

[1] *Bulletin*, Ill. St. Mus. Nat. Hist., No. 10. "*Poteriocrinus bozemanensis P. douglassi*, and *Platycrinus douglassi*;" *ibid.*, No. 12. "*Batocrinus douglassi, Rhodocrinus douglassi, R. bozemanensis, R. bridgerensis, Platycrinus bozemanensis, P. bridgerensis, Dichocrinus bozemanensis.*"

[2] Miller, *Jour. Cin. Soc. Nat. Hist.*, IV, 306–15; also Springer, *Am. Jour. Sci.* (3), XXVII, 97–103.

[3] *Professional Paper*, U. S. G. S., No. 16.

etc., suggest also a relationship with the Salem limestone fauna of the Mississippi Valley. The conditions are therefore similar to those in the Madison limestone of the North, and the interpretation of the faunal relations in that region can doubtless be extended to the more southern area.

MISSISSIPPIAN FAUNAS OF THE WESTERN CONTINENTAL PROVINCE

For a knowledge of the Mississippian faunas of the Great Basin region we are especially indebted to Walcott, who has described them from the Eureka district of Nevada.[1] The faunas occur at various horizons through a series of "Lower Carboniferous" limestones 3,800 feet in thickness, and are most remarkable from the fact that there is a general mingling of forms which, if found in the Mississippi Valley, would be considered as characteristic either of the Devonian, the Mississippian, or the Pennsylvanian. There is, however, a notable absence of the more conspicuous elements of the Mississippian faunas of the Mississippi Valley, such as the crinoids of the Osage faunas, the large Spirifers of the *S. striatus* type, the *Archimedes* and *Pentremites* of the Chester faunas, etc. None of the specialized Mississippi Valley faunas can be recognized. This basin must have been isolated, during Mississippian time, both from the Mississippi Valley and from the Rocky Mountain basins. The one point of faunal contact between the Great Basin and the Mississippi Valley is found in the presence of several of the peculiar Great Basin forms in the fauna of the Spring Creek limestone of northern Arkansas, among which *Rhynchonella eurekensis* and *Leiorhynchus quadricostatus* are perhaps the most notable. The age of the Spring Creek limestone is believed to be very close to that of the Ste. Genevieve limestone, at which time, perhaps, the Mississippian Sea had its greatest extension in the East. With this expansion of the sea there would seem to have been established a brief communication with the Great Basin region, of such a nature as to allow a group of these peculiar forms to migrate at least as far east as northern Arkansas. It is apparently impossible to correlate this incursion in the Great Basin, however, perhaps because of our imperfect knowledge, because the most notable of the immigrant species, *R. eurekensis*, has a long range in the Great Basin beds.

[1] *Paleontology of the Eureka District*, Monog., U. S. G. S., Vol. VIII.

DISCUSSION

Professor Calvin

The paper presents very fairly and fully the taxonomic relations of the Devonian and the Mississippian so far as Iowa is concerned. I should be disposed to question the propriety of correlating the Sweetland Creek shales of Muscatine County with any part of the Kinderhook. It is true that in Missouri beds which have been referred to the Kinderhook furnish *Ptyctodus* and some other Devonian types; but at Burlington the Kinderhook shales carry a fauna that, in practically all its aspects, is Carboniferous. On the other hand, the fauna of the Sweetland Creek shales is characteristically Devonian. Leaving out *Ptyctodus*, which may belong to either of the two formations, all the other life forms will be found to be distinctively Devonian. The Sweetland Creek beds furnish two species of *Synthetodus*, a form very common in the State Quarry limestone. Now the State Quarry limestone is in large part made up of imperfectly comminuted shells of that most intensely non-Carboniferous of all the Devonian types, *Atrypa reticularis*, with occasional shells of another almost equally intensely Devonian form, *Gypidula comis*. Fossils are rather rare in the Sweetland Creek beds, but all that have been noted are such as to exclude this formation from any close relation to the Kinderhook.

PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

BAILEY WILLIS
U. S. Geological Survey

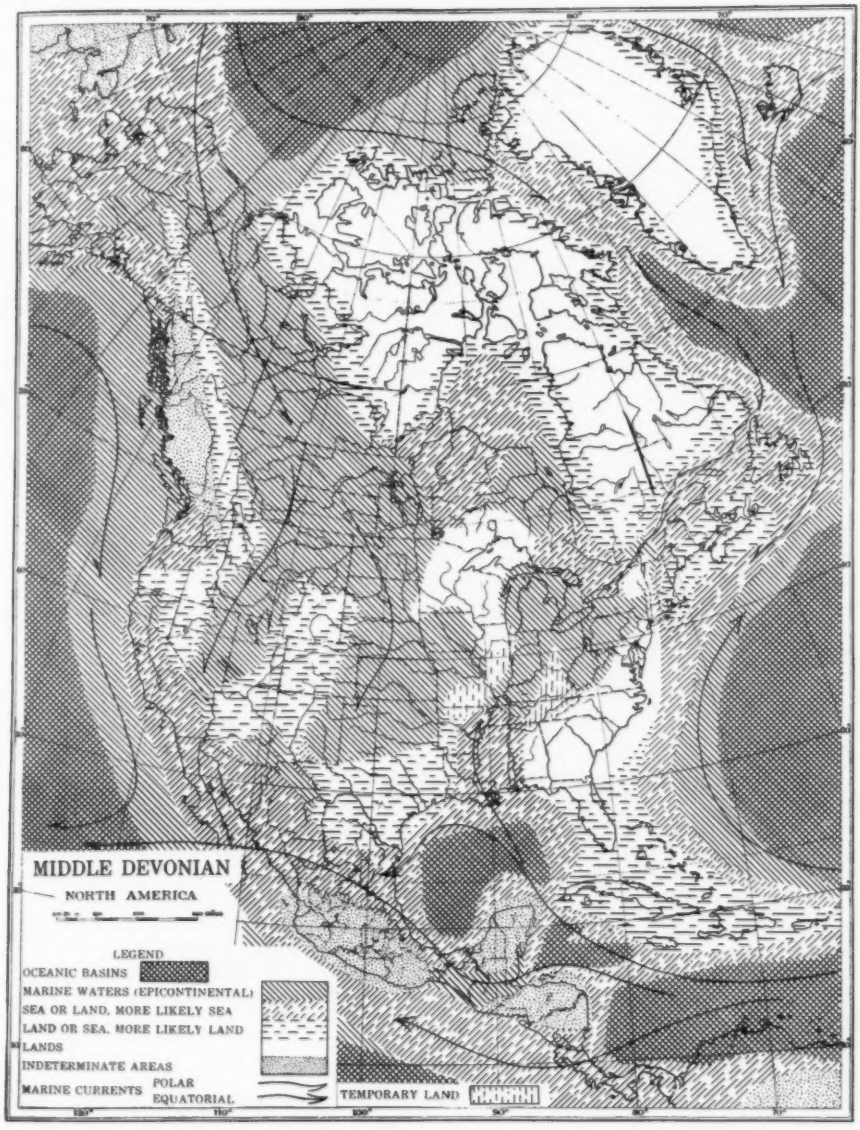
5. MIDDLE DEVONIAN NORTH AMERICA

The archipelagic condition of North America which began in the Ordovician persisted through the two succeeding periods with many changes of land and sea. Any refined study of these changes involves somewhat precise correlations which have already been carried far. The map here presented is of one passing phase only. The time represented is that before and after the invasion of the Hamilton fauna into the New York embayment, as is indicated by the temporary land barrier shown in Illinois and Missouri. The great thickness of sediments in the eastern Appalachian trough indicates marked orogenic movement during the middle and upper Devonian in the land lying toward the Atlantic. The southeastern expansion of the sea over Appalachia began apparently in middle Devonian and extended into upper Devonian time.

6. MISSISSIPPIAN NORTH AMERICA

The distribution and character of the Mississippian sediments leads to the inference that the time was one of an extended epicontinental sea with low and relatively limited lands. The archipelago of the immediately preceding period gave way to a general submergence of all the southwestern portion of the continent. In the far north conditions were favorable to the deposition of coal and other continental deposits associated with marine beds. The Atlantic and eastern portion of the interior sea and the wide sea covering all the western states present differences of habitat which are emphasized by Dr. Weller in his discussion. Toward the close of the Mississippian or early in Pennsylvanian time, an extensive land area emerged in the Colorado-New Mexico region, as indicated by erosion of the Mississippian sediments.

[1] Published by permission of the Director of the U. S. Geological Survey.


MIDDLE DEVONIAN
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
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LANDS
INDETERMINATE AREAS
MARINE CURRENTS
POLAR
EQUATORIAL
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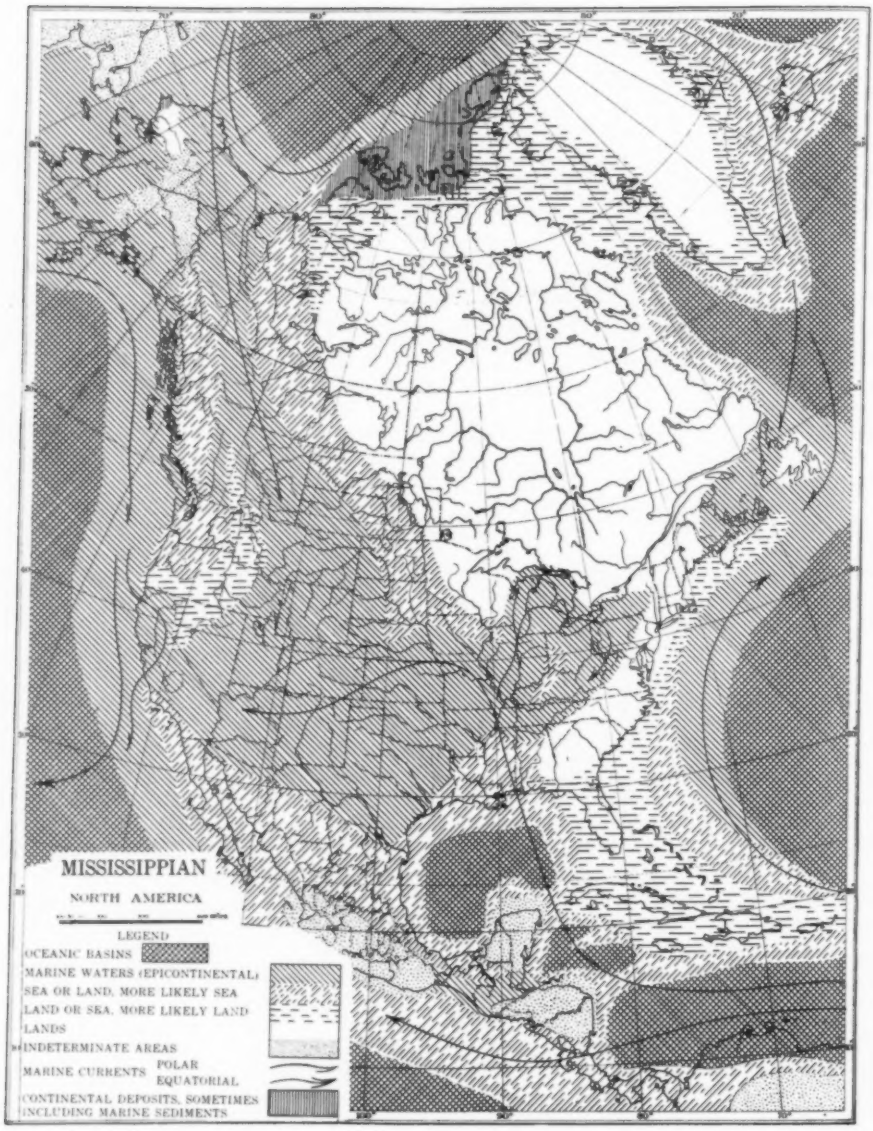
MISSISSIPPIAN
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LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
CONTINENTAL DEPOSITS, SOMETIMES INCLUDING MARINE SEDIMENTS

THE VALUATION OF UNCONFORMITIES

ELIOT BLACKWELDER
University of Wisconsin

The utility of unconformities in geology has long been recognized, and the historical significance of such structures is becoming more and more clearly understood. In the early days of geologic science only the more clearly visible unconformities involving discordance of strata were identified as such. Later it was shown that an irregular eroded surface between parallel beds may imply much the same conditions and events as the more conspicuous unconformities, except that deformation of the older rocks is not involved. The distinction was clearly made by Irving, in his admirable paper on the correlation of unfossiliferous rocks; the breaks accentuated by discordance were called "true unconformities," while those in parallel strata were styled "erosion intervals."[1] It was felt that the very word "unconformity" involved the idea of angular discordance between the beds above and below, and hence that any interruption between parallel beds must go by another name. In spite of this, however, the scope of the term unconformity has been gradually extended so that we find Le Conte, writing in 1890, combining breaks between discordant beds and eroded surfaces in parallel strata as merely two varieties of unconformity.[2] This usage is the one now generally followed by geologists (although the phrase *erosion interval* is still current), and it is in this sense that the term will be employed in the ensuing pages.

We now have several types of unconformities clearly distinguished: (*a*) eroded surface separating parallel strata; (*b*) contact between rocks of wholly unlike origin (for example, sandstone resting upon granite); and (*c*) angular discordance of beds with or without difference in lithologic character.[3]

[1] R. D. Irving, *U. S. Geol. Surv., Ann. Rep.*, VII, 1886, pp. 392, 393.

[2] Jos. Le Conte, *Elements of Geology*, 3d ed., 1893, p. 180.

[3] The phrase "eruptive unconformity," recently used to describe broad intrusive contacts of granite with older schists, is here excluded, on the ground that even if such structures are unconformities in any sense, they differ from erosional unconformities so fundamentally that the two cannot well be discussed together.

The criteria for identifying unconformites under varying conditions have been so carefully studied and systematized in recent years that they are generally well understood. The average student of geology knows that unconformities may be identified by means of basal conglomerates, by weathered zones on the underlying formations, by the truncation of dikes, faults, and other structures, by the general field-relations of the outcrops, by actually observed discordances and irregularities at contacts, and by still other means.[1]

At first the events signified by an unconformity were somewhat indefinitely realized. That the structure indicated an episode of erosion and the absence of strata which existed in other places, and that in some cases more or less disturbance had taken place in the intervening time, was clearly apprehended. Geologists are now generally agreed that an unconformity implies: (*a*) cessation of deposition (usually involving emergence, and often accompanied by deformation of the rocks); (*b*) denudation (usually by subaerial processes); (*c*) resumption of deposition (usually attending submergence, but often by terrestrial processes). It is also clearly understood that an unconformity represents a "lost interval," or lapse of time which is otherwise unrecorded at that place. The interpretation of this lost interval is the chief subject of the present paper, and is the one which most requires analysis and a definition of factors.

Writers of papers on stratigraphy not uncommonly state that a given unconformity is a great unconformity, or that another is a slight one; that it represents a vast lapse of time, or a minor episode only. The reader, however, cannot always know just what is meant by these expressions. From the context of such papers one may infer that the unconformity is considered great by one writer because of one feature, and by another because of a very different feature. A few examples will make this clear.

Regarding the unconformity at the base of the Keweenawan series, Van Hise says, ". . . . in areas in which the unconformity . . . . *is not great*, there is such a likeness in strike and dip of the two series as to suggest, at first, that the two are conformable."[2] Here apparently

[1] The criteria are exhaustively treated by Van Hise in a paper on the "Principles of Pre-Cambrian Geology," *U. S. Geol. Surv., 16th Annual Report*, Pt. I, 1896.

[2] "A Historical Sketch of the Lake Superior Region to Cambrian Time," *Jour. of Geol.*, I (1893), 127.

greatness is measured by the degree of discordance; the great unconformity being the one in which the lower series has been much more deformed than the upper, while the slight unconformity separates beds which have similar structure.

Walcott describes the break separating the Cambrian from the Belt series in Montana as a "slight unconformity"[1] because the dividing line is rendered very inconspicuous by the parallelism of the strata above and below. But on another page he refers to the same interruption as a "great stratigraphic unconformity,"[2] because it represents the loss of 3,000–4,000 feet of Algonkian strata by erosion. Here is an implication that an unconformity may be considered great if there is a large "lost interval," even if it is inconspicuous because the lower and upper beds are not discordant.

Referring to the unconformity between the horizontal beds of Ordovician and Carboniferous (Pennsylvanian) strata in eastern China, the present writer says:

> The absence of Silurian, Devonian and Lower Carboniferous series from Shantung indicates that the interval of erosion *may have* included all of those periods, and thus be worthy of rank as an unconformity of the first magnitude. It is possible, however, that sedimentation continued long after Ordovician time, and that the resulting rocks were subsequently removed by erosion, in all localities thus far examined. . . .[3]

In this case lapse of time is made the sole criterion of greatness, and is discriminated from stratigraphic break or thickness of strata missing.

To summarize these different usages, then. an unconformity is sometimes called great (*a*) because there is prominent discordance of structure, (*b*) because a great thickness of strata is lacking, or (*c*) because the making of the unconformity involved a long lapse of time. It is true that these factors may all apply to any one unconformity, but they do not necessarily agree with each other. Great stratigraphic break is usually regarded as implying great lapse of time, and hence the two ideas are often combined in discussions and the expressions are used as if they were equivalent. In the study

[1] C. D. Walcott, "Pre-Cambrian Fossiliferous Formations," *Bull. G. S. A.*, X, 211.

[2] *Loc. cit.*, 204.

[3] Bailey Willis, Eliot Blackwelder, and R. H. Sargent, *Research in China*, I, Pt. I (1907), pp. 48–49.

of ancient pre-Cambrian terranes, or others which are devoid of fossils, it may not be practicable to determine how great a thickness of the record is lost, and, much less, the time through which the land conditions endured. The term "great," then, has value as indicating the geologist's opinion that the discordance is pronounced and that it doubtless implies great loss of record. In this sense it is a convenient word and has been of much service. Nevertheless, for the sake of clearness, the three factors should be carefully discriminated wherever that is feasible, even if their value cannot be definitely appraised.

To show that the stratigraphic hiatus[1] is not necessarily a measure of the lapse of time during which the unconformity was being made, I may cite Le Conte, who says: "Every case of unconformity represents a gap in the geologic record at that place. . . . . The loss of record may be partly by erosion, but mostly because not written at that place."[2] Unquestionably the stratigraphic break represents a lapse of time not now recorded in that place. But the region may have continued to be the scene of deposition during a part of that time, and the strata thus formed, and carrying the record, have been removed in the ensuing period of erosion.

By way of illustration we may take two unconformities which are somewhat similar as regards the length of the unrecorded interval, but are very different in time-value. At Rome, Georgia, Tertiary strata rest upon folded Cambrian rocks. In the Bear Lodge Mountains, northwest of the Black Hills of North Dakota, Tertiary beds may also be found upon Cambrian strata at certain points. The lost interval in each section is represented by all the strata from late Cambrian to Tertiary. In the first case, however, the deposition of sediments continued with brief interruptions from Cambrian to at least Pennsylvanian times, and then apparently was supplanted by erosion from Permian to late Tertiary times. In the second case sedimentation persisted until the end of the Cretaceous period, and gave way to erosion only during the Eocene period. It is plain, therefore, that although the stratigraphic break is nearly identical in

[1] By this term is meant the gap in the strata; i. e., where Devonian lies on Cambrian, the *stratigraphic hiatus* is equivalent to the Ordovician and Silurian systems.

[2] Jos. Le Conte, *Elements of Geology*, 3d ed. (1893), p. 181.

the two sections, the time-value is very different, being equivalent to five to seven periods of geologic history in the Georgian region, but to only one period, or a fraction of a period, in Wyoming.

The same thing may be brought out by examining one of these two unconformities at different points. Fig. 1 represents diagrammatically the pre-Oligocene unconformity of the Black Hills region. In a section taken at (*A*) horizontal Oligocene silts (solid black) rest on folded Algonkian slates and granite; at (*B*) upon tilted Permian shales, and at (*C*) upon horizontal late Cretaceous sandstone and shale. Judged from the standpoint of structural discordance, the unconformity is very great at (*A*), moderate at (*B*), and nil at (*C*). Regarded from the basis of stratigraphic hiatus, it is greatest at (*A*), less at (*B*), and least, although still noteworthy, at (*C*). But the time-value is probably much the same at all three points. The

Fig. 1.—Pre-Oligocene unconformity in the Black Hills. The section is diagrammatic and generalized.

history of the region appears to be roughly this: Sedimentation was continuous from the Cambrian to the close of the Cretaceous period save for temporary episodes of erosion in mid-Paleozoic, and Jurassic times. No deformation attended these early changes, and the final result of the deposition was a thick blanket of strata lying horizontally across the region of the Great Plains. At the close of the Cretaceous period a low dome was bulged up, and during the Eocene the top of this was beveled off so that the pre-Cambrian rocks were exposed within encircling rims of younger beds. To this epoch of erosion the entire unconformity under discussion is due; and it would seem therefore that the time-value of the break is to be measured in this way rather than by the time-equivalent of the strata which are missing in any one section.

It appears, then, that unconformities seen in isolated sections may be prominent or obscure structurally, that they may represent a large or a small gap in the sedimentary column, and that they may

indicate a period of erosion of long or short duration, not to be estimated by the "lost record."

At this point it will be advisable to consider how these three factors may be determined with reference to a given unconformity. The degree of discordance may often be observed directly in sections, or may be inferred from observations of strike and dip. The stratigraphic hiatus may be discovered by correlating the beds above and below with a standard section of reference (supposing that such a section has been established), and thus determining what formations are lacking. These are matters of common knowledge and need not be dwelt upon here. The time-value, however, is not so easily ascertained, since observations on one section, or even on several adjacent sections, are not sufficient to bring out the facts. Let us start with the generally understood principle, ably presented in recent years by Chamberlin and Salisbury,[1] that *all unconformities are presumably limited in extent;* when traced in any direction they are eventually lost in a conformable sequence of strata. Thus the present eroded surface of North America—a future unconformity—merges into the continuous sediments of the seas about its borders. But some parts of this land mass have been out of water much longer than others, and so the unconformity which is to be will have a different time-value in different places. For example, if the sea-level should rise steadily the sea would encroach upon the land. With it would come the sedimentation for which it furnishes the conditions. In the southern Great Plains these modern sediments would lie first upon the Quaternary beds of the Gulf border. As the sea has been only recently excluded from this strip, the time-value of the intervening unconformity would be small—probably a fraction of the Quaternary period. Further slow advance of the sea would allow somewhat later deposits to be laid over a surface which seems to have been land since Miocene times. Continued encroachment would eventually allow deposits of still later age to be spread upon land which has been eroded presumably since the Eocene epoch. Here evidently the time-value is greater than in either the first or the second locality. The events and time-intervals are expressed graphically in the accompanying diagram (Fig. 2). This particular unconformity, it will be observed, began

[1] T. C. Chamberlin and R. D. Salisbury, *Geology* (1906), II, 222–24.

to be developed at *C* in Eocene times and ceased to be made at *C* in the fifth post-present epoch. Its time-value reaches its maximum at that place, covering ten to eleven epochs, while at the present Gulf coast (*A*) its value decreases to zero. This illustrates in a very simple way the principle that most unconformities gradually increase or decrease in time-value from place to place; that there is a waxing and a waning phase corresponding to recession and incursion of the sea or to the shifting of the sites of continental deposition. If the recession or invasion is very rapid, the lower or upper line of our diagram will approach the horizontal, but such changes will be matters of degree, not of kind.

Actually, however, the relations are rarely as simple as this, nor

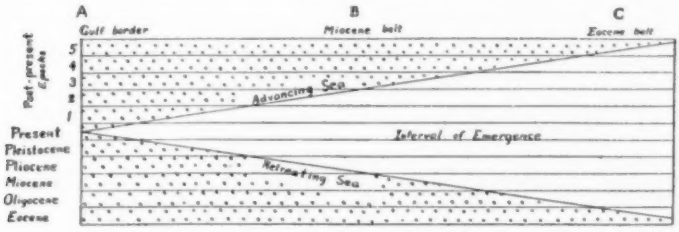

Fig. 2.—Diagram of a simple unconformity. The dotted area represents sedimentation, the blank space erosion. The horizontal lines denote equal time.

are the advances and retreats as regular. In the case just given it will also be observed that the stratigraphic hiatus varies almost directly with the time-value, a phenomenon which is somewhat common among unconformities, but is by no means the rule.

A case of average complexity may be formulated by imagining the middle Atlantic seaboard of the United States to be gradually submerged (Fig. 3). In an early stage of the encroachment of the sea modern sediments would be laid down upon Pleistocene sand and clay in the Chesapeake region (*A*); farther west younger beds would rest upon Miocene (*B*)—much as in the Texas example. Still later beds, however, would overspread the Piedmont belt with its ancient crystalline rocks. The discordance would suddenly change from slight to very great (*C*); and likewise the hiatus, which was equivalent to Tertiary-Modern on the coastal plain, would quickly expand to

a gap embracing perhaps Algonkian-Modern. Assuming as correct the current view that the Piedmont at this point was submerged in the Ordovician[1] period, but not later, we find that the time-value has also changed from Miocene-Modern to Ordovician-Modern, a great and relatively abrupt change, but not so great as that observed in the hiatus. Farther westward (*D*) submergence would cause modern sediments to be laid upon the truncated edges of the Paleozoic strata in the Appalachian Valley and Mountains. The discordance here is less, although still great, and the stratigraphic hiatus has decreased to perhaps Ordovician-Modern. The region is believed to have been eroded ever since the Permian period, and so the time-value is Permian-Modern. Now supposing the submergence to lap over upon the Allegheny plateau (*E*), angular discordance is quickly

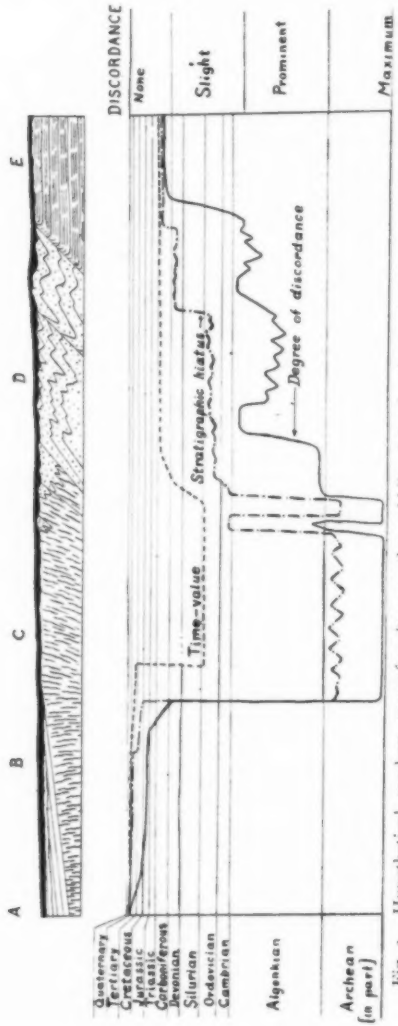

Fig. 3.—Hypothetical modern unconformity on the middle Atlantic slope. Positions on the diagram of curves coincide with similar positions on the generalized section.

[1] N. H. Darton, *Am. Jour. Sci.*, 3d series, Vol. XLIV (1892), pp. 50–52.

reduced to insignificance (although the eroded surface itself would be very uneven). Stratigraphic hiatus decreases to a value of Pennsylvanian-Modern. Time-value, however, suffers no corresponding change from the previous locality.

It appears then that the three factors, discordance, hiatus, and time-value, may vary suddenly and largely, but that they do not necessarily vary in the same degree, or even in the same phase. Time-value may decrease while hiatus increases. Discordance may occasionally become more pronounced as the lost record becomes smaller.

These considerations lead to the conception that unconformities are constantly fluctuating features of the stratigraphic record. It is also plain that the time-value of an unconformity can be determined only through the study of the geologic history of a considerable region, while discordance and hiatus can often be ascertained from individual sections.

The hypothetical case just considered, of an unconformity in eastern United States, fails, however, to give a complete picture of that unconformity since the assumed case represents only one withdrawal and advance of the sea. As a matter of fact we are to think of such a region as the Piedmont belt, or, let us say for the present example, the Canadian shield of ancient rocks, as being a land nucleus of varying dimensions, now expanding by withdrawal of the epicontinental sea, until it includes a continent, and then contracting to a mere island, perhaps smaller than Greenland, as the sea overspreads its shelving surface. These advances and retreats have taken place, not once, but many times, and the result is quite as many unconformities, *all of which blend landwards into one far greater unconformity* which records the continuous land condition of the central nucleus.

This is illustrated by Fig. 4, which shows an interpretation[1] of the submergences and emergences of a part of central United States since pre-Cambrian times, with the corresponding sedimentary series and unconformities. Vertical spaces represent periods of time, while on the horizontal line are scaled off certain broad provinces stretch-

[1] In this and other examples used in the present discussion the facts are but imperfectly known, nor does the writer profess to have made an exhaustive study of even those which are available. His interpretation of the history is not in any way essential, but will serve the purpose of illustrating the general principles.

ing from Labrador on the northeast (to the right) to southern Texas on the southwest (to the left). On the right, one sees that Labrador has been eroded from some time before the Cambrian down to the glacial period; and even then the deposition was accomplished by glaciers—a terrestrial agency. The unconformity there represents

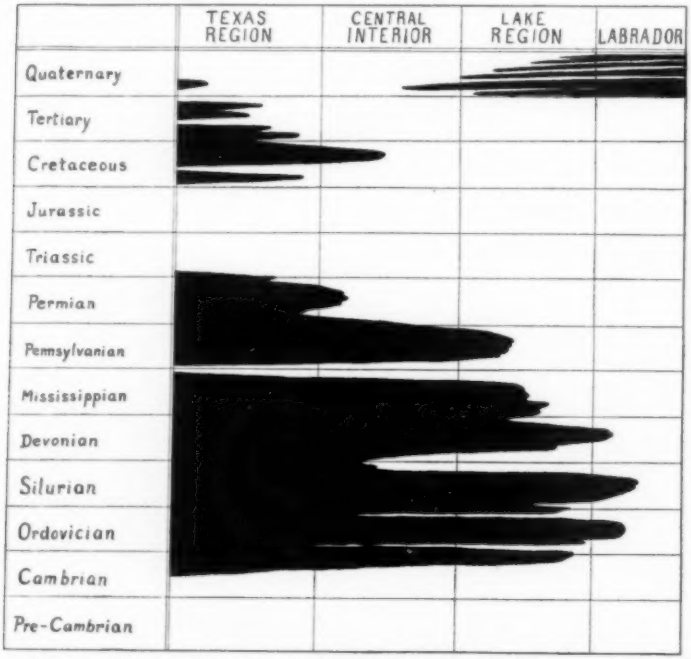

Fig. 4.—Diagram of an unconformity with lateral extensions and restrictions. The extent and duration of the principal periods and areas of sedimentation, with their corresponding rock systems, are shown in solid black. The white, on the other hand, denotes the time and extent of erosional conditions and corresponding unconformities.

a vast and presumably uninterrupted lapse of time. When traced southwestward, however, this great denudation-interval branches into many minor intervals which are intercalated between periods of sedimentation—the times during which the so-called sedimentary record was produced. The minor unconformities dovetail in with the sedimentary series, especially around the borders of the continent.

Traced toward the old land nucleus, the many little unconformities merge into a few, and finally into one all-inclusive unconformity. Traced seaward, the sedimentary wedges of the record expand into continuous piles of marine strata; for over much of the oceanic abysses sedimentation has probably been uninterrupted since the Archean period or before.

Our more familiar unconformities are to be thought of, then, as temporary expansions or wedge-shaped extensions of greater unconformities, and we must not be surprised if, when traced in one direction, they dwindle to nothing,[1] or if in another direction they expand so as to swallow up the entire sedimentary record.

SUMMARY

In the preceding discussion, the writer seeks to show that the words "great" and "slight" as applied to unconformities are often ambiguous and in need of definition; that, where these things can be determined, it is important to know whether the *structural discordance*, or the *stratigraphic hiatus*, or the *duration of erosion*, is the thing that is great or small.

It appears that the stratigraphic hiatus or lost record is not necessarily a measure of the time which elapsed while the unconformity was being produced. The two may be nearly equal, but on the other hand the lost time may be much less than the lost record. It cannot well be greater.

Also, all three factors change from place to place—the discordance and hiatus often suddenly and capriciously, the time-value usually more gradually.

Many, if not most, unconformities are merely lateral extensions of much more persistent unconformities. The main unconformity denotes a very long duration of terrestrial erosive conditions, while the projecting wedges record the backward and forward migrations of belts of sedimentation around the borders of that land.

The entire geologic record then is not to be conceived of as a pile of strata, but as a dovetailed column of wedges, the unconformities and rock systems being combined in varying proportions. The former predominate in some places and periods, while the latter prevail in others.

[1] This conception is admirably explained by Chamberlin and Salisbury in *Geology*, II, chaps. iv, v.

Reviews

Early Devonic History of New York and Eastern North America. By John M. Clarke. New York State Museum, Memoir 9, 1908.

Our knowledge of the Paleozoic faunal history of North America is derived largely from the faunas of the interior epicontinental seas which were spread out upon the continent from time to time, sometimes as great tongue-like embayments, and again as great sheet-like expansions which covered large areas of the continental surface. These shallow epicontinental seas teemed with life and the sediments deposited in them are frequently abundantly fossiliferous. The various elements in these faunas usually give evidence of being immigrants, and the originating tracts in which they were evolved are believed usually to have been in shallow areas on the borders of the oceanic basins. In these border regions having more direct communication with the permanent oceanic basins, the physical conditions were doubtless more nearly continuous than in the more or less transient interior epicontinental seas, and the life history also was probably less liable to abrupt changes. At the present time the Paleozoic rocks of most of the border region of the continent are deeply buried beneath the sea or beneath younger strata, the most notable exception to this condition being found in the great eastern angle of the continent which includes the maritime provinces of Canada. Because of their peculiar relations to the faunas of the interior, any contribution to our knowledge of the ancient faunas of these maritime provinces is received with especial favor. A most notable contribution to the paleontology of this region is a memoir on the *Early Devonic History of New York and Eastern North America*, by the Director of Science of the New York Education Department, which is devoted to a discussion of the lower and middle Devonian faunas of the Gaspè region.

Before entering upon a description of the faunas to be considered, Dr. Clarke has sketched the geology of the region which was first worked out by Sir William E. Logan many years ago. A glowing tribute is rendered this great pioneer in the investigation of Canadian geology, who "sought and found the key to the geologic structure of the country; and so conclusively and with such admirable finish was the work of this master hand accomplished that in all the years since elapsed, from 1844 and 1845, little has been added to, and naught subtracted from his achievements."

The Gaspè peninsula is the northeastern extremity of the Appalachian mountain system, and the geologic structure consists of a series of parallel folds similar to those so well known farther to the southwest, and formed by the same great earth disturbances. The Devonian rocks with whose faunas the memoir is concerned lie unconformably upon older Paleozoic formations. They include the Gaspè limestones and sandstones of Logan. The Gaspè limestone attains a thickness of 2,010 feet and is frequently highly fossiliferous. Three divisions are recognized, the St. Alban limestone below, followed by the Bon Ami limestone, and this again followed by the Grand Grève limestone. The Gaspè sandstones, according to Logan's estimates, attain the enormous thickness of 7,000 feet, but this estimate may be too large by reason of the repetition of some beds by faulting.

From the St. Alban beds a fauna of 51 species is described "of which fully one-half occur in the typical Helderbergian faunas (Coeymans and New Scotland) to the southwest." The fauna of the Bon Ami limestone is small and of much less importance, but the Grand Grève limestone has furnished a fauna of about 150 recorded species. This fauna

> has a less proportion of community of species with the Helderbergian but still a substantial number of species (21 identities and 14 close affines). With the Oriskany there is a larger community of species (39 identities and 13 affines) and so commanding is this percentage and the composition of the congeries itself, consisting as it does of the most typical species of the Oriskany, that it compels this inference: The development of the Oriskany fauna was synchronous with the prevalence of the Helderbergian fauna in this region and the differentiation of the two faunal elements, which we commonly recognize in the Appalachian regions as Helderberg and Oriskany, was subsequent in date to the development of the combined faunas together in Gaspè. Thus again we have evidence that the Gaspè basin was a center of dispersion of these two faunas and that the direction of this dispersion so far as the facts now indicate was still toward the southwest.

The marine fauna of the enormously thick Gaspè sandstone is of but limited extent, and occurs in a comparatively thin horizon of calcareous sandstones which probably lies near the base of the entire series. This great accumulation of arenaceous sediment seems to have been deposited in a great costal lagoon into which terrigenous sediments were rapidly swept. The stratum of marine sediments probably represents overwash of the outside waters in time of stress, bringing in the marine organisms which are now found as fossils. Only about fifty species are recorded in this fauna of which "one-seventh to one-sixth are survivors of the Oriskany element in the Grand Grève limestones. With the Hamilton faunas from

the calcareous shales of the Skaneateles, Moscow, and Ludlowville formations of New York, this Gaspè sandstone fauna presents a predominant agreement, having sixteen identities and six affines, or approximately 50 per cent. of the fauna." The presence of this Hamilton element in the fauna is indicative, according to Dr. Clarke, of an invasion of the latter fauna from the west, while the earlier Helderberg-Oriskany fauna still occupied the sea in the Gaspè region. An alternative interpretation, the invasion of the Hamilton fauna from the south along the Atlantic border, should perhaps be considered. The Onondaga fauna is not differentiated in the Gaspè region, it being one of the undifferentiated elements in the Grand Grève fauna.

The evidence is thus fairly cumulative that the Gaspè basin was an area of rapid evolution during the early Devonic and a center of dispersion from which the lines of immigration departed westward. We cannot now say that they did not also lead thence eastward. In a later Devonic stage this basin was the recipient of migrants from the west. The course of migration into and out of the interior Appalachian waters was along a seaway which cannot yet be traced step by step, but evidently parallel to the Appalachian folds. There seems now a fair presumption of a continuous connection between the Gaspè basin and the east by way of the Connecticut trough into eastern New York. The tangible evidence of this connection will be set forth more fully hereafter. The Gaspè Eodevonic basin extended from the Canadian Archean shield at the north to the limit of the Dalhousie beds on the south and contracted in the middle Devonic. Apparently there was no free and open connection between it and the parallel contemporaneous embayments at the south in which the Chapman and Moose River sandstones of Maine were set down.

The faunas described in this Memoir are illustrated by 48 finely executed lithographed plates which are fully up to the standard so long established and maintained by the State of New York in her paleontologic publications. Not the least attractive feature of the book is the frontispiece, a reproduction in color of the painting by Frederick James of that most striking landmark of the Gaspè coast, Percé Rock.

S. W.

Textbook of Petrology. By F. H. HATCH. New York: Macmillan.

This book, which is a fifth edition, revised and rewritten, contains a summary of the modern theories of petrogenesis, a description of the rock-forming minerals, and a synopsis of the chief types of igneous rocks and their distribution as illustrated by the British Isles. The work is concise and somewhat comprehensive and may serve very well for an introduction to the study of igneous rocks, with the aid of the microscope. Part I treats

of the physical characters of igneous rocks, their mode of occurrence, structure, texture, and composition. In Part II some seventy pages are devoted to mineral descriptions, and in the back of the book are four pages of tables to be used for the determination of the common rock minerals. The usefulness of this part of the work would be greatly increased if it contained a colored plate showing the maximum birefringences of minerals for various thicknesses of plates. It is presumed that the student has a knowledge of optics. Part III is devoted to the classification of igneous rocks, the method being essentially the qualitative system now in use. Part IV devotes about one hundred pages to the distribution of igneous rocks of Great Britain. This part of the work is illustrated by many text figures and is a brief summary of the petrography of the British Isles. The work is well arranged and includes much useful data. The American student of igneous rocks could wish for a rather more comprehensive treatment of differentiation, magmatic stopping, and related subjects; with a brief résumé of the quantitative system of rock classification, the use of which is increasing on this continent.

W. H. E.

The Ephemeral Volcanic Island in the Iwôjima Group. By T. WAKIMIZU. Publication of the Earthquake Investigation Committee in Foreign Languages, No. 22, Section C, Art. 1. With Plates I–XII. Tôkyô, 1908.

The island appeared February 1, 1905, three nautical miles east of M. Iwôjima. It was three miles in circumference, 480 feet in height and contained about 200 acres in area. The lava was of the olivine-augite-andesite type resembling closely that of Mt. Pipe in Iwôjima. From its geographic position and nature of ejecta it seemed clear that the ephemeral island was a volcano belonging to the same volcanic line as the three principal volcanic islands of the Iwôjina group. On June 16, 1905, the island had almost disappeared. The cause of submergence was attributed to the erosive action of the waves and possibly to depression of the crater rim.

C. J. H.

Formation of Geodes with Remarks on the Silicification of Fossils. By RAY S. BASSLER. From the Proceedings of the United States National Museum, Vol. XXXV, pp. 133–54, with Plates XVIII–XXIV. Washington, 1908.

The author finds in his study of the formation of geodes in the Keokuk geode beds and in the shales and limestones of the Knobstone division of the

Mississippian that their origin is often traceable to a beginning in fossils. The geodes are invariably found in or near joint planes and rifts along which waters have had easy passage. A large majority of the geodes in the Knobstone may be traced to an origin in a fractured crinoidal stem or brachiopod shell. In all the specimens described deposition of silica in the fractures has been preceded by a complete silicification of the fossil itself. The crystallizing force of the addition of silica in the fracture continues to rupture the fossil more and more which later forms a typical geode.

The author maintains that the replacement of the original calcareous material of fossils by silica in siliceous pseudomorphs does not take place at the time of deposition of sediment, but rather that silicification proceeds as weathering advances. It has been observed that limestones yielding siliceous pseudomorphs contain in the unweathered portions calcareous fossils. The embedded part of the fossil is often calcareous while the exposed part is siliceous. From these lines of evidence he concludes that silicification of many fossils is a present process. C. J. H.

Mineral Resources of the Philippine Islands. By WARREN D. SMITH, Chief of the Division of Geology and Mines. 39 pp., 6 pls., map. Manila, 1908.

This bulletin marks the beginning of an annual statement of the mineral production of the islands. The plan adopted is similar to that of the U. S. G. S.

The nonmetallic products are first considered. A low-grade, subbituminous coal, suitable as a gas-producer, is mined. It is abundant, but coal-mining is difficult owing to complex folding and faulting. Some of the mines are promising. A good quality of lime is manufactured at Binangouan. Raw materials for the manufacture of cement are abundant. The limestone is very free from magnesia. Mention is made of natural gas, petroleum, building and monumental stone, abrasives, gypsum, phosphates, sulphur, salt, magnesite, mineral waters, Fuller's earth, mica, manganese, and precious stones. The brick, tile, porcelain, and pearl industries are of little importance.

Gold is the only metal now mined to any notable extent. A profitable mine is worked in Benguet. Deposits of copper, silver, lead, iron, and tellurium occur, but are not actively mined.

Production in 1907: gold, 4,540 oz., silver, 83 oz., iron, 436 tons, coal, 4,545 tons. C. J. H.